DOE/OR/07-2038&D1

Seismic Investigation Report for Siting of a Potential On-Site CERCLA Waste Disposal Facility at the Paducah Gaseous Diffusion Plant Paducah, Kentucky

CLEARED FOR PUBLIC RELEASE

APPENDIX C

TECHNICAL MEMORANDUM FOR THE SITE-SPECIFIC FAULT STUDY INITIAL ACTIVITIES

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August 2002

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FIGURES

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ACRONYMS

BJC	Bechtel Jacobs Company LLC
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
GPR	ground-penetrating radar
p-wave	compression (P) wave
PGDP	Paducah Gaseous Diffusion Plant

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1. INTRODUCTION

Representatives and support staffs of the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the Commonwealth of Kentucky, worked together to develop a field investigation program to address seismic issues associated with potentially siting a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) waste disposal facility at the Paducah Gaseous Diffusion Plant (PGDP). These planning efforts for conducting the Seismic Investigation Program at Site 3A are described in the *Seismic Assessment Plan for Siting of a Potential On-Site CERCLA Waste Disposal Facility at the Paducah Gaseous Diffusion Plant* (BJC 2001a) and an evaluation of National Environmental Protection Act values (BJC 2001b). Site 3A consists of 110 acres situated immediately south of the PGDP security fence (Fig. C.1). The Seismic Investigation Program consisted of three primary tasks: a Paleoliquefaction Study, a Fault Study, and a Geotechnical Study. These three tasks are documented in five technical memoranda.

The Fault Study was comprised of two components, a regional Fault Study and a site-specific Fault Study. The site-specific Fault Study was in turn conducted in two phases: the "initial activities" and the "follow-up activities." Each of these phases is documented with a separate technical memorandum. This technical memorandum documents the site-specific Fault Study "initial activities," which included high-resolution compression (p-wave) seismic reflection survey and the ground penetrating radar (GPR) calibration survey activities. The site-specific activities were conducted at Site 3A and the regional Barnes Creek site, which is located approximately 11 miles northeast of the PGDP in Massac County, Illinois (Fig. C.2).

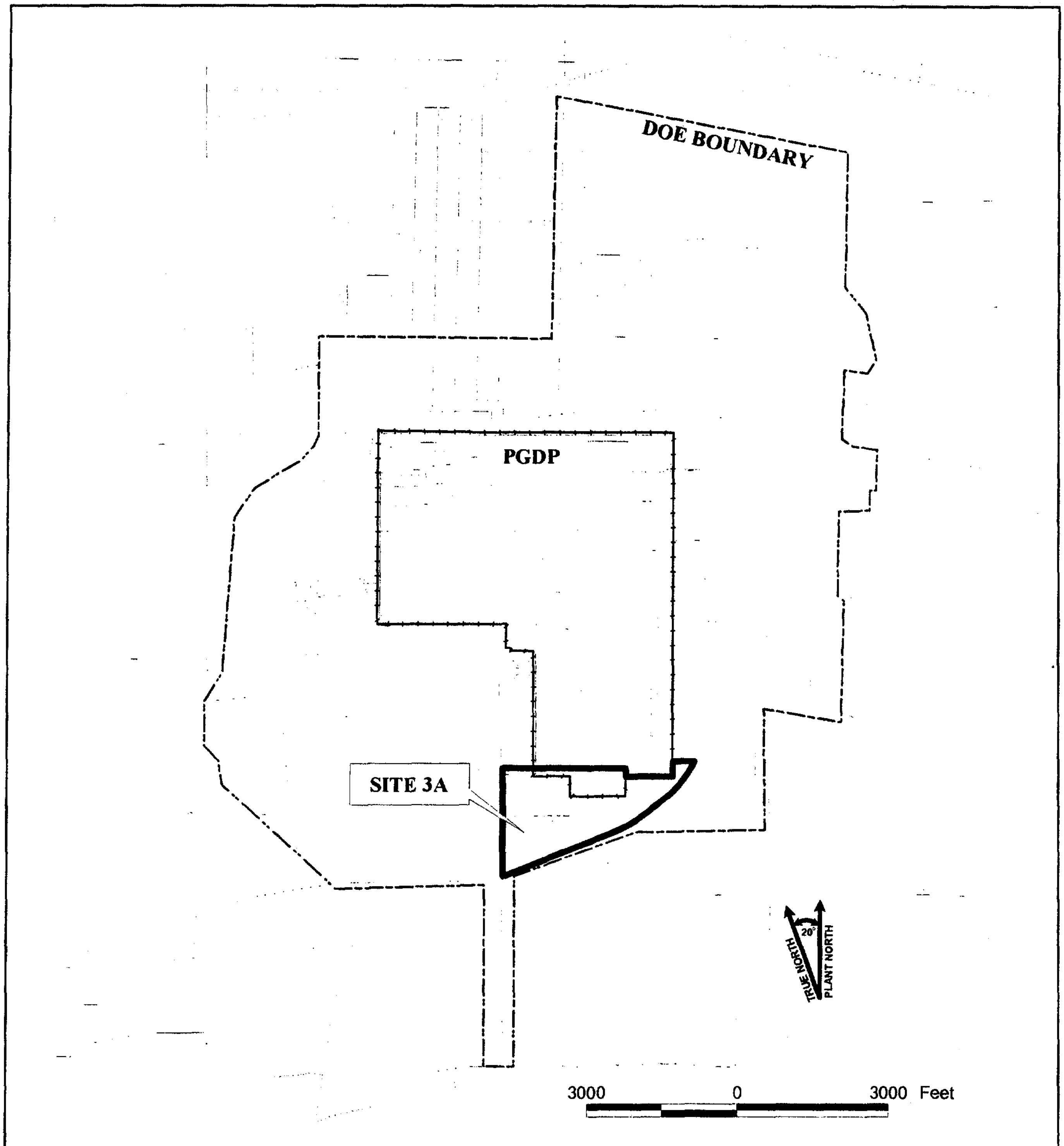
2. P-WAVE SEISMIC REFLECTION SURVEY

A seismic reflection survey is a nonintrusive geophysical method that uses acoustic energy to image the subsurface. A summary of this geophysical technique is presented in Attachment C-I of this technical memorandum. The purpose of the p-wave survey was to determine whether anomalies are present that may suggest the presence of potential young faults at Site 3A. For this study, the term "young fault" is defined as faults that show displacement/deformation of the top of the Paleocene-aged Porters Creek Clay. If the results of this survey indicated that young faulting exists at Site 3A, then DOE would proceed with the remaining components of the site-specific Fault Study.

2.1 PLANNED ACTIVITIES

The planned p-wave survey activities are described in Sect. 3.1.1.1 of Part II of the Seismic Assessment Plan as follows (BJC 2001a):

> Five lines totaling approximately 16,800 ft will be run.... This 24-channel 6-fold survey will be conducted using a geophone spacing of one meter, an elastic wave generator source, and a geophone frequency of approximately 40 Hz. The results will be processed using Winseis© or ProMax™ software. The final stacked data will include unenhanced sections and separate enhanced sections (with migration, etc.). Results will be presented in time domain with cross-references to expected depths of key reflections.



LEGEND:
FENCE
ROAD
STREAM
DOE BOUNDARY
SITE 3A BOUNDARY

U.S. DEPARTMENT OF ENERGY
DOE OAK RIDGE OPERATIONS
PADUCAH GASEOUS DIFFUSION PLANT

BECHTEL JACOBS COMPANY LLC
MANAGED FOR THE US DEPARTMENT OF ENERGY UNDER
US GOVERNMENT CONTRACT DE-AC-05-98OR22700
Oak Ridge, Tennessee • Paducah, Kentucky • Portsmouth, Ohio

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Fig. C.1. Location of Site 3A.

FIGURE No. c5ac90001sk529.apr
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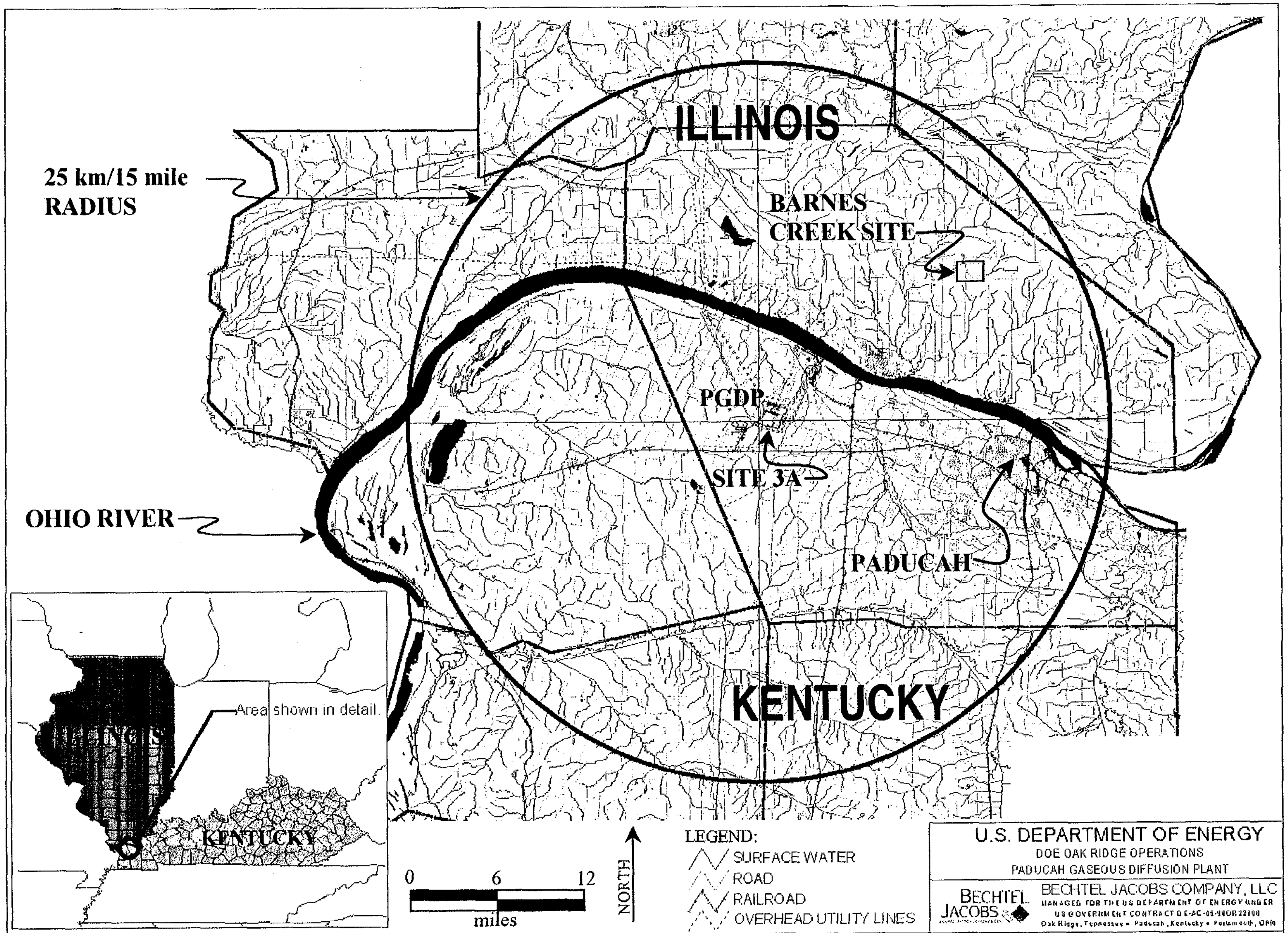

Fig. C.2. Location of PGDP and the Barnes Creek site.

2.2 SUMMARY OF WORK PERFORMED

The p-wave survey was performed by SAIC Engineering, Inc., and its subcontractor, Blackhawk GeoServices. SAIC is under subcontract to Bechtel Jacobs Company LLC (BJC), DOE's Management and Integration contractor.

Site preparation consisted of laying out the locations of the survey lines at Site 3A. The five survey lines (seven segments) were then established by a licensed land surveyor in accordance with the Seismic Assessment Plan. The survey lines were marked on 100-ft intervals with wooden stakes and shot points marked every 5 ft. Attachment C-II contains the surveyed coordinates of each of these stations. (Note that the stations are 5 ft apart, or there are 20 stations per 100 ft.) Figure C.3 illustrates the locations of each survey line at Site 3A.

After site preparation was completed, testing of various p-wave energy sources was conducted at Site 3A. Although this testing phase was not included in the Seismic Assessment Plan (BJC 2001a), DOE proposed to conduct tests of three p-wave sources (e.g., hammer and cylinder, accelerated weight drop, and Minivib) and a vibratory shear wave source. The purpose of these tests was to determine which source produced the best results at Site 3A. Each of these sources are described in Attachment C-I of this technical memorandum.

DOE held a teleconference with EPA and the Commonwealth of Kentucky on October 10, 2001, and reached consensus on conducting the proposed tests. The tests were conducted along Line L4 from November 12–14, 2001. After the data were processed, subject matter experts and representatives from DOE, EPA, and Commonwealth of Kentucky met to evaluate the test data on November 15, 2001. It was agreed that the Minivib and the hammer and cylinder sources provided adequate results, with the Minivib providing better results. Primarily because of noise created by multiple strikes of the weight, the accelerated weight drop source was rated as inadequate for this survey. It was agreed that the p-wave survey should be conducted with the Minivib truck-mounted unit, and the hammer and cylinder was the preferred backup energy source in those areas that were inaccessible to the Minivib (Kentucky 2001).

After the source testing was completed, the p-wave survey was conducted along the survey lines from November 15 to December 2, 2001. Blackhawk GeoServices processed the data, and their final report is contained in Attachment C-I of this technical memorandum. The Blackhawk GeoServices report contains detailed information regarding the data acquisition, data processing, and interpretation of results.

2.3 DEVIATIONS FROM PLANNED ACTIVITIES

During the p-wave survey, there were two deviations from the Seismic Assessment Plan (BJC 2001a).

First, the plan called for five lines (six segments) to be run. Five lines (seven segments) actually were surveyed. Line L5 was divided into two segments (i.e., Lines L5A and L5B) to remove a "dogleg" that originally was planned for Line L5, which allowed the data to be processed properly. Additionally, because of safety concerns, geophones were not planted across two major roadways (i.e., Hobbs Road and Dyke Road); however, the multi-fold data still provided coverage beneath these roadways at the depths of interest. The regulators concurred with this deviation prior to its implementation. These deviations did not reduce the quality of the p-wave survey.

Second, the Seismic Assessment Plan called for a "24-channel 6-fold survey [to] be conducted using a geophone spacing of one meter, an elastic wave generator source, and a geophone frequency of approximately 40 Hz." The actual survey conformed to recognized state-of-the-practice procedures and used a 144-channel,

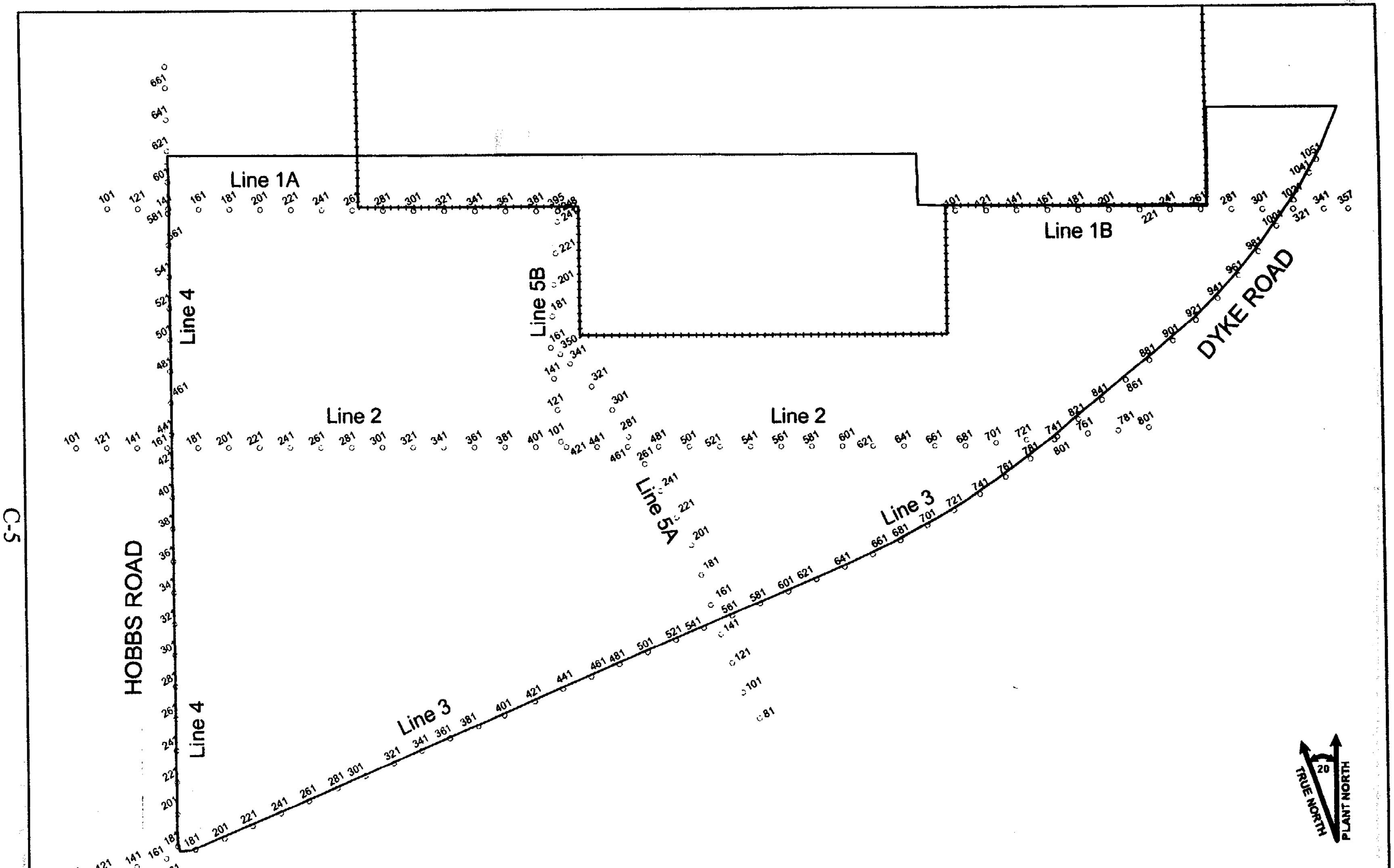

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Fig. C.3. Location of p-wave seismic lines at Site 3A.

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24-bit seismograph to record the 36-fold survey data. The 40Hz vertical component geophones were placed at 5-ft intervals and "shots" (using the selected energy source) were taken at 5-ft intervals. As previously described in Sect. 2.2 of this technical memorandum, site-specific testing was conducted to determine the most effective energy source and configuration for use at Site 3A. These deviations were made to enhance the quality of the p-wave survey data (Kentucky 2001).

2.4 DATA ACQUIRED

The results of the p-wave survey are presented in Attachment C-I of this technical memorandum. The attachment consists of the *Final Seismic Survey Report* prepared by Blackhawk GeoServices. It contains processed data from the source tests and each survey line (including enhanced stacks, grayscale enhanced stacks, uninterpreted instantaneous phase sections, and interpreted instantaneous phase sections).

2.5 SUMMARY OF RESULTS

The resolution of the p-wave survey data was considered excellent for its intended purpose. Several horizons were successfully imaged beneath Site 3A, including the top of Mississippian-aged limestone bedrock, Cretaceous-aged McNairy Formation (lower sand facies), and portions of the Porters Creek Clay. The results of the p-wave survey were presented to EPA and the Commonwealth of Kentucky for review, and the results were discussed at a meeting held January 15, 2002, among DOE, EPA, and the Commonwealth of Kentucky (PPC 2002). Based on the p-wave survey results, a mutual agreement was reached to continue the site-specific Fault Study, and the locations of the follow-up horizontal shear wave seismic reflection survey were identified (PPC 2002).

3. GPR CALIBRATION SURVEY

GPR is a nonintrusive, electromagnetic, geophysical survey method used to image the shallow subsurface. A summary of this geophysical technique is presented in Attachment C-III of this technical memorandum. Because previous attempts to use GPR technology at PGDP have resulted in poor resolution of geologic features, the purpose of the GPR calibration study was to conduct a limited, site-specific test to determine whether the GPR was capable of penetrating local clays and silts to identify shallow (less than 20 feet) subsurface features. If GPR was determined to be successful at identifying known, shallow faults at the Barnes Creek (Illinois) site during the calibration test, then GPR could possibly be used to identify potential, similar features at DOE Site 3A.

3.1 PLANNED ACTIVITIES

The planned GPR calibration survey activities are described in Sect. 3.1.1.2 and 3.2.2 of Part II of the Seismic Assessment Plan as follows (BJC 2001a):

> A GPR calibration survey will be conducted at Barnes Creek (approximately 11 miles northeast of PGDP) to the extent necessary in readily accessible areas to determine if GPR is capable of penetrating the clays and silts at the site and identifying known faults. This calibration survey will be conducted/initiated using a suite of antennae up to a maximum 50-MHz tool. Approximately 1500 ft of GPR data will be acquired in an attempt to correlate data collected at the ground surface features observed in a parallel streambed. If the GPR is able to identify subsurface features to a depth of 10 ft, then it will be considered successful and will be employed at Site 3A.

The Barnes Creek site is located in Massac County, Illinois (Sect. 9, Township 15 South, Range 5 East).

3.2 SUMMARY OF WORK PERFORMED

The GPR calibration survey was performed by SAIC and its subcontractor, Blackhawk GeoServices. SAIC is under subcontract to BJC, DOE's Management and Integration contractor. The GPR calibration survey was conducted by three seismic experts from Blackhawk GeoServices, SAIC, and Jacobs Engineering Group. A fourth seismic expert from the Kentucky Geological Survey was present for the GPR calibration survey to represent the Commonwealth of Kentucky. The GPR calibration survey was conducted at the Barnes Creek (Illinois) site, and a follow-up calibration survey was conducted at Site 3A.

The GPR calibration survey was initiated at the Barnes Creek site on December 5, 2001. To begin, a 1,600-ft long line was established approximately 50 ft north of Barnes Creek running parallel to Barnes Creek (Fig. C.4). The survey line was marked with wooden stakes every 100 ft and painted lines every 10 ft. The line began at Orchard Road and extended west toward Barnes Creek Road. The seismic-induced features (Nelson et al. 1998) that are visible in the bank of Barnes Creek were mapped with respect to the stations along the 1,600-ft test line, realizing that the features were expected to generally trend northeast-southwest. The following features were mapped at the following stations:

- east end of Westerman graben located at 800-ft station,
- west end of Westerman graben located at 1,080-ft station,
- "high fault" located at 1,270-ft station, and
- westernmost (small) fault located at 1,330-ft station.

In order to conduct a "blind test," this information was not provided to the seismic experts from Blackhawk GeoServices, Jacobs Engineering Group, and the Kentucky Geological Survey, and they were not allowed to view the features in Barnes Creek.

At the Barnes Creek site on December 5, 2001, four GPR surveys/tests were conducted using different frequencies to determine which would provide the best penetration. The first survey was conducted along the entire 1,600-ft test line using a 200 MHz antenna. The efficacy of subsequent surveys was determined without surveying the entire length of the test line. The second survey was conducted along 1,500 ft of the test line using a 100 MHz antenna. The third survey was conducted along the western 1,100 ft of the test line using an 80 MHz antenna. The fourth survey was conducted along the western 1,100 ft of the test line using a 16 MHz antenna. Blackhawk GeoServices processed the data collected from the Barnes Creek site. During the morning of December 6, 2001, the seismic experts from Blackhawk GeoServices, SAIC, Jacobs Engineering Group, and the Kentucky Geological Survey met to review the data. The experts agreed that data from the 200MHz antenna offered the highest resolution and best correlation with the mapped features (PPC 2002). Based on these results and changing weather conditions, the group agreed to discontinue the calibration survey at the Barnes Creek site (i.e., they decided not to conduct surveys/tests using 48 MHz or 32 MHz antennas), and they agreed to continue the GPR calibration survey at Site 3A.

On the afternoon of December 6, 2001, a 750-ft long test line was established at Site 3A along p-wave survey Line 5B from stations 201 to 351 (note that there are 5 ft between p-wave survey stations). Two GPR surveys/tests were conducted. The first survey was conducted along the test line using a 200 MHz antenna. The second survey was conducted along the test line using a 40 MHz antenna. Blackhawk GeoServices then processed the data and provided the information to the seismic experts at SAIC, Jacobs Engineering Group, and the Kentucky Geological Survey for review. The final report from Blackhawk GeoServices is contained in Attachment C-III of this technical memorandum.

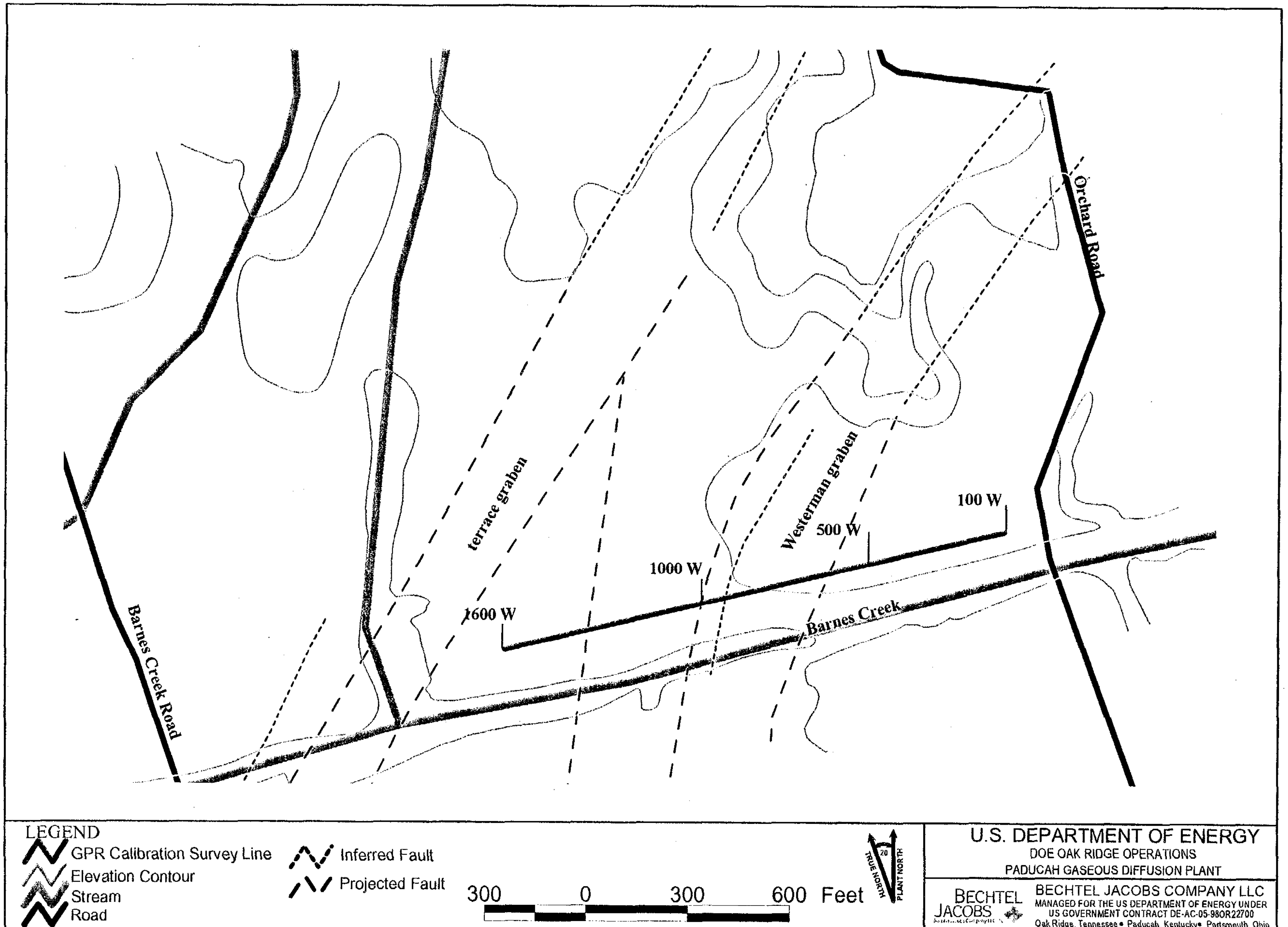

Fig. C.4 Location of GPR calibration survey at the Barnes Creek study area.

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FIGURE No. c5ac90001sk533.apr
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3.3 DEVIATIONS FROM PLANNED ACTIVITIES

During the GPR calibration survey, there were two deviations from the Seismic Assessment Plan (BJC 2001a).

First, the original plan called for the use of "a suite of antennae up to a maximum 50-MHz tool." The 50-MHz limit was discussed later with experts from the Commonwealth of Kentucky, however, who agreed that 50-MHz qualifier should not be a limiting factor for this survey. The testing at the Barnes Creek site was conducted using four separate antennas (i.e., 16, 80, 200, 100, and MHz). The higher frequency antennas actually penetrated the subsurface geology at the Barnes Creek site better than the lower frequency antennas. The testing at Site 3A was conducted using two antennas (i.e., 40 MHz and 200 MHz). These deviations did not reduce the quality of the testing, because they allowed a wide range of antenna frequencies to be tested. This was considered when deciding the antennas to test at Site 3A.

Second, the plan called for the GPR calibration survey to be conducted only at the Barnes Creek site. The first four tests were conducted at the planned location and were successful in determining which frequencies could identify subsurface features. Following the successful, efficient testing at Barnes Creek, the DOE investigation team chose to conduct an additional, site-specific test of the equipment at Site 3A. This deviation did not reduce the quality of the testing, because it provided additional, unplanned site-specific data that indicates neither the high frequency nor the low frequency antenna can penetrate the geology at Site 3A, even though the 200 MHz antenna can penetrate the geology at the Barnes Creek site.

3.4 DATA ACQUIRED

The results of the GPR calibration survey are presented in Attachment C-III of this technical memorandum.

3.5 SUMMARY OF RESULTS

The GPR calibration survey achieved its intended purpose. The survey indicates that neither high nor low frequency GPR will provide suitable resolution of the geology at Site 3A; therefore, no GPR survey was recommended for Site 3A. The survey also indicates that high frequency GPR (e.g., 200 MHz) will provide the greatest resolution of the geology at the Barnes Creek site to provide useful information; therefore, a follow-up GPR survey was recommended for the Barnes Creek site. The results of the GPR calibration survey were presented to the EPA and Commonwealth of Kentucky for review, and the results were discussed at a meeting held January 15, 2002, among the DOE, EPA, and the Commonwealth of Kentucky (PPC 2002).

4. REFERENCES

BJC (Bechtel Jacobs Company LLC) 2001a. *Seismic Assessment Plan for Siting of a Potential On-Site CERCLA Waste Disposal Facility at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, BJC/PAD-207, Final, Bechtel Jacobs Company LLC, Kevil, KY, September.

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Kentucky 2001. "P- and SH-wave Seismic Reflection Field Test Comments from Dr. Woolery," memorandum from Dr. John Volpe, Cabinet for Health Services, to Don Seaborg, DOE, December 11 (transmitted in e-mail dated December 19).

Nelson, John W, F. Brett Denny, Leon R. Follmer, and John M. Masters,1998. "Quaternary grabens in southernmost Illinois: deformation near an active intraplate seismic zone," *Tectonophysics*, 305, pp. 381–397.

PPC (Project Performance Corporation) 2002. "PGDP CERCLA Waste Disposal Strategy Project Core Team Meeting, January 15, 2002," final, e-mail dated February 11.

ATTACHMENT C-I

P-WAVE SURVEY RESULTS

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BLACKHAWK
GeoServices
Southeast Region

FINAL
SEISMIC SURVEY REPORT

Site 3A Seismic Assessment
Paducah Gaseous Diffusion Plant

Paducah, Kentucky

Blackhawk GeoServices Project No. 2901SAI

Prepared for

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March 8, 2002

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EXECUTIVE SUMMARY

Representatives and support staffs of the U.S. Department of Energy, the U.S. Environmental Protection Agency, and the Commonwealth of Kentucky, have developed a field investigation program to address seismic issues associated with potentially siting a CERCLA waste disposal facility at the Paducah Gaseous Diffusion Plant. The results of these investigations will be used as input to the feasibility study of disposal options for CERCLA-derived waste.

One of the potential disposal facility sites presently under consideration is Site 3A. This site is located on DOE property, south of the present security fence. As part of the planned field program, approximately 16,000 linear feet of p-wave seismic reflection data were collected to identify potential subsurface anomalies that may indicate the presence of faults. The target zone for the p-wave survey extends from the bedrock surface (located at a depth of approximately 320 feet below ground surface) upward into the overlying McNairy and Porters Creek Clay Formations.

The p-wave seismic reflection survey was successful in imaging several horizons beneath Site 3A, including the top of limestone bedrock, top of the McNairy, and portions of the Porters Creek Clay. A total of eleven north-northeast trending faults have been interpreted in the data. Relative movement along the interpreted fault blocks appears to be complex, with generally horst and graben structures in the eastern portion of the survey area, and blocks that have rotated, or dip, toward the west in the western portion of Site 3A.

The overall trend and geometry of the faulting in bedrock generally is similar to faulting observed in the Fluorspar Area Fault Complex of Massac County, Illinois, located across the Ohio River.

All eleven interpreted faults show disruptions near the top of the bedrock limestone and appear to offset that unit. Nine of the eleven faults are interpreted to extend upward into the Cretaceous-age McNairy Formation. Several of these features may extend well into or possibly through the Paleocene-age Porters Creek Clay Formation.

It is important to stress that this p-wave reflection survey does not have sufficient resolution to determine if the postulated faulting extends into the gravel deposits, fine-grained continental deposits and/or Quaternary aged loess that are thought to overlie the Porters Creek Clay. This will require a more focused s-wave seismic reflection study that targets the very shallow sediments located immediately above these interpreted faults, as well as the analysis of soil borings and/or the collection of direct push samples.

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) is the lead agency at the Paducah Gaseous Diffusion Plant (PGDP). The general location of PGDP is presented in **Figure 1**. The U.S. Environmental Protection Agency (EPA) and the Commonwealth of Kentucky pursuant to the Federal Facility Agreement (FFA) regulate environmental restoration activities at PGDP.

Over the past year, representatives from EPA, the Commonwealth of Kentucky, and DOE and their support staffs have developed a field investigation program to address seismic issues associated with potentially siting a CERCLA waste disposal facility at the PGDP (BJC 2001). The results of these investigations will be used as input to the feasibility study of disposal options for CERCLA-derived waste at PGDP. One of the potential disposal facility sites presently under consideration is referred to as Site 3A. This site is located on DOE property, south of the present security fence **(Figure 2)**.

As part of this field investigation program, Blackhawk GeoServices (BHG), in partnership with our subsidiary, Bay Geophysical, performed a p-wave seismic reflection survey at Site 3A from November 13 to December 2, 2001. The work was performed under subcontract number 4400047316 with Science Applications International Corporation (SAIC).

For this study, p-wave seismic reflection data were acquired along seven survey lines totaling approximately 16,000 linear feet of surface coverage. The locations of the survey lines relative to PGDP and other permanent geographic features are shown in **Figure 2**. For production work, key seismic equipment used to collect the data included:

- Industrial Vehicles International (iVi) T-15000 Minivib,
- 144-channel OYO DAS-1 Seismograph,
- 40-Hz OYO SMC40 vertical component geophones.

This report summarizes all data acquisition and field methods used to conduct the investigation, and includes sections on data processing, interpretation, conclusions and recommendations.

1.1 PROJECT OBJECTIVES

The purpose of the Site 3A p-wave seismic reflection survey is to identify potential subsurface anomalies that may indicate the presence of faults. The target zone for the p-wave survey extends from the bedrock surface [located at a depth of approximately 320 feet below ground surface (bgs)] upward into the overlying McNairy and Porters Creek Clay Formations. If the initial p-wave reflection survey shows no indication of deformation in the sediments overlying the bedrock, then it may be considered that no young faulting is present and no follow-up activities will be necessary. Conversely, if deformation of the overlying sediments (especially the Porters Creek Clay) is indicated, then additional follow-up activities, (including an s-wave survey) may be conducted to determine if the deformation extends up into the even younger near surface loess and fine-grained continental deposits.

1.2 GEOLOGIC SETTING

Site geology is thought to consist of varying thickness sand, silt, and clay units from the surface to an estimated depth of 320 feet bgs, where limestone bedrock occurs. Quaternary aged loess and fine-grained continental deposits overlie gravel deposits at a depth of approximately 20 feet bgs. Key reflection horizons at Site 3A lie below the loess, continental deposits, and gravels. These units are the Paleocene-age Porters Creek Clay Formation, the Cretaceous-age McNairy Formation, and the limestone bedrock. The 55 to 60 million year-old Porters Creek Clay Formation occurs at a depth of approximately 30 to 55 feet bgs and is underlain by the McNairy Formation from approximately 125 to 320 feet bgs. The McNairy is generally a sandy formation, interbedded with varying thickness silt and clay units. Mississippian-age limestone bedrock underlies the McNairy Formation.

The bedrock, McNairy, and Porters Creek Clay units are thought to be laterally continuous across Site 3A and to possess a reasonably high acoustic contrast relative to adjacent units, such that seismic reflections likely will be seen in the data. Consequently, the initial p-wave seismic reflection survey focused on looking for faulting in these units. Based on the regional geologic setting and mapping in the Fluorspar Area Fault Complex of Massac County, Illinois located just across the Ohio River from Paducah, Kentucky, if faulting is present at the PGDP, it would be expected to trend northeast and consist mostly of high-angle normal faults that outline horsts and grabens (Nelson 1998).

2.0 DATA ACQUISITION

This section describes the seismic methods and field procedures used to conduct the Site 3A investigation including survey control, source testing, and production parameters.

2.1 GENERAL

Seismic Reflection Technique

Seismic reflection profiling is a standard technique employed by the oil and gas exploration industry. The use of this technique in shallow engineering and environmental projects has been a relatively recent phenomenon, as the formerly high production costs and serious computing requirements were prohibitive. Advances in microelectronics have led to engineering seismographs and PC-based processing that now permit the cost-effective use of reflection seismic methods in a wide variety of applications (Steeples and Miller 1988).

Details of the general seismic reflection technique can be found in many comprehensive texts, such as Sheriff and Geldart (1995); therefore, only a brief synopsis of the technique is included in this report. A discussion of the problems associated with the seismic reflection technique used in this survey is provided in Section 2.2.

Seismic Reflection

The basic principles of the reflection technique are illustrated in **Figure 3**. The seismic reflection method involves projecting acoustic energy down from the surface, and then recording the acoustic energy back at the surface as it reflects off of formations at depth. Seismic energy is also reflected, refracted, and diffracted at boundaries in the subsurface, in accordance with Snell's Law. The main design consideration for a successful seismic reflection survey is the ability to separate the reflected energy from the other arrivals in processing.

A seismic reflection occurs when an acoustic wavefront encounters an impedance boundary in the subsurface. Seismic impedance depends on both the velocity and density of a rock, and impedance boundaries occur where these rock properties change abruptly, usually due to changes in lithology. The reflection coefficient, R, across an interface, is expressed by a function relating the acoustic impedance of adjacent layers. R determines the relative amplitude of the reflected wavelet.

$$\mathbf{R} = \frac{\sigma_2 \mathbf{V}_2 - \sigma_1 \mathbf{V}_1}{\sigma_2 \mathbf{V}_2 + \sigma_1 \mathbf{V}_1}$$

where,
R = reflection coefficient,
σ_1, σ_2 = mass density of the material on each side of the interface, and
V_1, V_2 = p-wave velocity on each side of the interface.

The sign of the reflection coefficient determines the polarity of the reflected wave. The magnitude of the reflection coefficient is critical to obtaining usable data. The seismic reflection technique will not work if the acoustic contrast is not sufficient to produce a clear reflection, regardless of the survey parameters or processing techniques employed. The ability of the seismic reflection method to detect an individual sedimentary bed is not only a function of the acoustic impedance at the top and bottom of the bed, but also depends on the layer thickness. The minimum resolvable bed thickness is often quoted as 1/4 to 1/8 of the wavelength of the seismic reflection. Wavelength is inversely proportional to frequency.

That is:

$v = f\lambda$

where, v = acoustic propagation velocity,
f = frequency, and
λ = wavelength.

λ controls vertical resolution and is obviously dependent on frequency and velocity.

Sedimentary limestone rock in the PGDP area occurs at a depth greater than 250 feet, and is generally hard and possesses high acoustic velocities. Compressional wave (p-wave) velocities of these rocks range from approximately 15,000 to 20,000 feet per second. Overlying the limestone bedrock are the lower density silty sands of the McNairy Formation and the silty clays of the Porters Creek Clay Formation. Compressional wave velocities of these rocks range from approximately 2,500 to 4,000 feet per second at depth. The frequencies put into the ground by the Vibroseis sources ranged from 30-350 Hertz (Hz) and recoverable frequencies ranged from 50-200 Hz. **Table 2-1** compares the frequencies, velocities and wavelengths for the site area, with consideration to the data acquisition parameters used and recovered signal frequencies.

TABLE 2-1

VELOCITY, FREQUENCY, AND WAVELENGTH RELATIONSHIPS FOR TYPICAL PGDP SEDIMENTARY ROCKS

Velocity ft/s	Frequency Hz	Wavelength ft	Vertical Offset Mapping Limit (1/4 λ), ft	Vertical Offset Detection Limit (1/8 λ), ft
3,000	100	30.0	7.5	3.8
3,000	120	25.0	6.3	3.1
3,000	140	21.4	5.4	2.7
3,000	160	18.8	4.7	2.4
3,000	180	16.7	4.2	2.1
4,000	100	40.0	10.0	5.0
4,000	120	33.3	8.3	4.2
4,000	140	28.6	7.2	3.6
4,000	160	25.0	6.3	3.1
4,000	180	22.2	5.6	2.8
5,000	100	50.0	12.5	6.3
5,000	120	41.7	10.4	5.2
5,000	140	35.7	8.9	4.5
5,000	160	31.3	7.8	3.9
5,000	180	27.8	7.0	3.5
15,000	60	250	62.5	31.3
15,000	80	188	47.0	23.5
15,000	100	150	37.5	18.8
15,000	120	125	31.3	15.6
15,000	140	107	26.8	13.4
18,000	60	300	75.0	37.5
18,000	80	225	56.3	28.1
18,000	100	180	45.0	22.5
18,000	120	150	37.5	18.8
18,000	140	129	32.3	16.1
20,000	60	333	83.3	41.6
20,000	80	250	62.5	31.3
20,000	100	200	50.0	25.0
20,000	120	167	41.8	20.9
20,000	140	143	35.8	17.9

When a reflecting boundary exists, it is important to optimize the field procedure and acquisition parameters to ensure the quality of the final processed data. Choosing the best field parameters involves determining the relative importance of several competing objectives, such as site constraints, equipment capabilities, and processing needs.

In all geophysical surveys, the objective is to extract the usable data (i.e., in this case, reflections from various lithologic boundaries) from the unwanted background information (geologic and ambient noise). In reflection seismology, it is desirable to record high frequency, high signal-to-noise ratio reflection events from the boundary of interest. The frequency of a reflection event is largely determined by the source input frequency and the filtering effect of the ground. Often, the target reflector frequency is similar to that commonly recorded for coherent noise (in particular, the noise from ground roll), making it difficult or impossible to selectively filter out the noise. Isolation of the reflection events requires careful design of field acquisition parameters, such as the source/receiver geometry, choice of source and receiver types, as well as recording parameters, such as sampling rate and filter settings. The choice of these parameters is discussed in Section 2.2.

It is sometimes difficult to separate the near surface refraction from early reflection events in the recorded data of reflection surveys. On a common depth point (CDP) gather, refraction events tend to stack with lower frequencies than reflections. Occasionally, the refraction events seem to "ring" (have multiple peaks and troughs for a single event) through a record and mask reflection arrivals. Careful examination of each record is necessary to ensure that a refractor is not being incorrectly interpreted as a reflection event. Geological logs and analysis of arrival times can often help discriminate between these two.

A sample shot record from Line 3 **(Figure 4)** demonstrates the relationship between the reflection, refraction, airwave, and ground roll events. The refraction event, highlighted in purple, is always the first to arrive at the long offset geophones and usually makes up the bulk of the first breaks. Refractions are characterized by linear moveout across the shot records; that is, they appear as straight segments. The reflection events, which dominate the areas highlighted in blue, are characterized by a hyperbolic moveout. The reflections identified in this shot record are those from the limestone bedrock. Multiple reflections, though not clearly evident in this shot record, result from a double bounce of acoustic energy between say, the surface and the top of the limestone. Multiples display nearly the same hyperbolic moveout as primary reflections and are typically easy to recognize. Some multiples <u>do</u> stack in on the final sections, and any interpreters working with this data need to be aware of their presence.

The ground roll is highlighted in yellow. It is typically lower in frequency than the reflection or refraction events, but can be very high in amplitude, masking the reflection events. However, it can often be filtered out of the records by using frequency or dip filtering. Also highlighted on **Figure 4** is an airwave event, highlighted in orange. This is energy that propagates directly through the air from the source to the geophones. It travels at a slower velocity than seismic energy traveling through the ground; however, it typically has a very broad frequency range and can have a very high amplitude. This event is typically removed by muting (mathematically cutting out the signal), because frequency filtering is often ineffective.

<u>**Shear Wave Technique**</u>

The seismic reflection technique can be divided into two categories based on the type of source used. Compressional, or p-waves, propagate through the earth as a change in pressure, and are the same as the sound waves we hear. Particle motion for p-waves is parallel with the direction of propagation of the wave. Shear waves, or s-waves, propagate through the earth by shearing adjacent particles. Particle motion in s-waves is perpendicular to the direction of wave propagation.

Where site conditions are favorable and the depths of interest nearer the surface, the s-wave technique is valuable for two main reasons. First, for a given frequency, shear waves will have approximately half the wavelength of the corresponding P waves. Although shear waves do not propagate as far through the earth as compressional waves, when offsets are short (such as in most engineering or environmental applications), shear waves will provide approximately twice the resolution. Secondly, shear waves cannot propagate through liquids or gases, as these forms of matter have no shear strength. Thus, shear waves are much more sensitive to fracturing than their compressional counterparts, making them the most useful tool for finding and delineating fractures.

2.2 DESIGN OF SURVEY PARAMETERS

A summary of the production data acquisition parameters is provided in Section 2.5 and **Table 2-2**. For this project, the receiver group interval was 5 feet, with one 40-Hz vertical component geophone located at each station. Shot records contain 144 live channels in a symmetric split spread configuration, except at the beginning and end of each line, where the iVi Minivib was rolling on and off of the spread. Data were recorded with a 0.5-millisecond (msec) sample rate and a record length after correlation of 500 msec. The source parameters were determined by on-site testing.

2.2.1 Source Testing

Four seismic energy sources were tested along the northern portion of Line 4 **(Figure 2)** to determine whether an impulsive or vibratory source would yield the most useful and high frequency data to satisfy the project objectives. Stacked sections representing each of the sources are presented in **Appendix A**. The sources tested included:

- Hammer and Cylinder – impulsive p-wave;
- Accelerated Weight Drop (AWD) – impulsive p-wave;
- T-15000 iVi Minivib – vibratory p-wave; and
- Microvib – vibratory s-wave.

Impulsive sources are more often used and best suited for seismic refraction surveys where ground roll is not a concern and for some types of shallow reflection work. Impulsive sources used to conduct the Site 3A source test included both the hammer and cylinder and the AWD.

Typically, the advantages of using a vibratory source for reflection work include a higher signal-to-noise ratio when compared to impulsive sources, such as the hammer and cylinder, weight-drops, or dynamite. This is due to the statistics of the correlation process and the ability to control the frequencies put into the ground. Another advantage is that particle motion amplitudes are much lower with vibratory sources, greatly reducing or eliminating damage to any nearby surface structures. This is because the energy of a vibratory source is input into the ground over a relatively long time interval.

Vibratory sources function by holding a plate on the ground and vibrating the plate through a user-defined range of frequencies, known as a "sweep." The length of the sweep, peak force, and frequency range can be changed in the field. At the instant the vibrator begins its sweep, the seismograph begins recording the signals received from the geophones. The seismic signal created by the sweep is received by the geophones and stored in the seismograph. By correlating the recorded signals from the geophones with the known sweep generated by the vibrator, a seismic trace is obtained.

For this project, the electromechanical microvibrator was used as the shear wave source. The microvibrator is coupled to the ground by eight large spikes (or smaller spikes depending on site conditions). It generates a sweep by oscillating a mass through a user-defined range of frequencies, which are transmitted into the ground.

<u>**Frequency Content**</u>

For vibratory sources, the frequency content of seismic reflection data is initially a function of the beginning and ending frequencies of the sweep, the length of the sweep, and the ground coupling. For impulsive sources, the frequency content of seismic reflection data is initially a function of the force exerted at the time of impact, and the ground coupling. A factor affecting data quality from both source types, is the transmission and attenuation of various frequency components in the subsurface, often termed the "earth response."

In general, there are two primary objectives in designing a sweep for high-resolution reflection surveys:

- To record useful seismic signals at the geophones with as high a frequency as possible; and
- To start the low end of the sweep such that the appropriate depth of penetration is achieved without generating intolerable ground roll.

With the start of fieldwork on November 13, 2001, source parameter testing was carried out on the north end of Line 4. The receiver interval and geophone array had been determined before the start of the survey. Sweeps of varying frequency bandwidths were recorded into a full (144 trace) split spread configuration in an effort to bracket the usable frequencies returning to the geophones from the subsurface. The initial testing, aided by frequency filtering in the recording instruments, determined that the following source parameters best achieved the objectives of broad bandwidth, good depth of penetration, and minimal ground roll generation:

- Hammer and Cylinder – 9 stacks / shotpoint;
- AWD – 6 stacks / shotpoint;
- iVi Minivib – 4 sweeps of 30-350 Hz over 6 seconds; and
- Microvib – 4 sweeps of 30-200 Hz over 6 seconds.

After the source test data were collected, stacked sections representing each of the 4 sources were reviewed by technical staff supporting the Project Core Team and a consensus reached to proceed with a p-wave survey using the iVi Minivib along each of the survey lines. Where surface conditions were too wet or muddy for the iVi Minivib truck, it was determined that the hammer and cylinder would be used as the energy source.

2.3 SITE-SPECIFIC PROBLEMS

In addition to the general requirements for seismic data acquisition described in Section 2.1, two site-specific problems were known to exist or became apparent during the Site 3A survey.

Wet and/or Muddy Areas

Wet and/or muddy areas were encountered along each of the survey lines, except for Lines 3 and 4 that were shot adjacent to Dyke and Hobbs Roads, respectively. The most laterally extensive muddy area occurred along most of the eastern half of Line 2. On November 16, the iVi Minivib truck got stuck about 250 feet west of Dyke road on survey Line 2. As a result, most of the data along this line were acquired using the hammer and cylinder.

Overhead Power Lines

Power lines often cause 60 and 120 Hz noise on some receiver channels due to induction from the surrounding electromagnetic field into the geophone elements. Power line noise problems are most severe when the ground is damp. Line 2 paralleled an overhead power line corridor; and Lines 3, 4 and 5A crossed the same power line corridor. Only minor effects were evident in the data, and were mitigated by applying a notch filter during data processing.

2.4 HEALTH AND SAFETY (H&S)

The Site 3A seismic survey was conducted under the Health and Safety Plan prepared by SAIC. SAIC personnel provided health and safety coverage. The survey was completed safely. As noted above, however, the iVi Minivib truck got stuck on survey Line 2. During attempts to free it from the mud a wire rope failed; however, this activity was conducted safely, and there were no injuries involved.

2.5 PRODUCTION PARAMETERS AND LINE INFORMATION

The nominal spread configuration is graphically represented in **Figure 5**. Production parameters for the seven Site 3A seismic lines are summarized in **Table 2-2**.

TABLE 2-2
NOMINAL SEISMIC REFLECTION ACQUISITION PARAMETERS

Shot Spacing	10 feet
Geophone Group Interval	5 feet
Nominal CDP Fold	36
Maximum Offset	357.5 feet
Minimum Offset	2.5 feet
Spread Geometry	Symmetric Split Spread 72/72 – (715 foot total active array)
Seismograph	2 OYO DAS-1 Recorders (Master/Slave)
Number of Channels	144
Sample Rate	0.5 ms
Record Length	0.5 second
Field Filters	3/18 – Out Hz/dB
Seismic Source	iVi MiniBuggy I, - 6,000 lbs of peak ground force 30 to 350 Hz, Linear, 6 second sweep, 4 sweep/station
Geophones	1 X 40 OYO SMC-40
Cables	48 pair cables with Amphib Heads, 13' takeouts, 24 takeouts / cable
Rollbox	I/O Inc. RLS-240M

Table 2-3 lists the lines surveyed and their number of stations. The lines are also shown on the seismic line location map **(Figure 2)**.

TABLE 2-3
SUMMARY OF LINE AND STATION NUMBERS

Line Name	First Station	Last Station	# of Stations	Line Feet
1A	101	395	295	1470
1B	101	357	257	1280
2	101	801	701	3500
3	101	1051	951	4750
4	101	675	575	2870
5A	81	351	271	1350
5B	101	248	148	735

2.6 PRODUCTION PROCEDURES

A Kentucky-licensed surveyor under the supervision of SAIC project personnel surveyed each line. Stations were staked and XYZ coordinates shot on 100-foot centers. SAIC personnel chained out stations on 5-foot centers and provided supplemental elevation shots, where necessary at high and low surface areas along each survey line. All XYZ coordinates were used by the seismic data processor to position the data, and perform statics analysis and datum corrections.

At the start of each line, the source was positioned at the first receiver station. Approximately 270 strings of geophones and 16 cables were mobilized to the field, allowing the crew to lay out the receiver spread well in advance of the recording. A total of 9 cables (216 channels) were connected to the OYO DAS-1 seismographs via the roll box at each recording vehicle set-up. The roll box selects the active geophones for each shot. An RTS-100 radio trigger box was also connected to the seismographs. This box was in radio communication with a similar unit in the Minivib. When the operator pushed the trigger button in the recording truck, a signal was sent to the vibrator to start the sweep sequence, and the OYO DAS-1 seismographs were triggered to start recording. During the sweep, the RTS-100 box in the vibrator transmitted a synthetic pilot sweep signal, generated by the Minivib's onboard computer, back to the RTS-100 box in the recording vehicle. This pilot sweep was recorded on auxiliary channel 2 in the master seismograph for correlation with the recorded data from the geophones. The uncorrelated data was written to the hard drive and to 4mm data tape. Correlated records were generated and written to tape after the completion of a line.

Typical field operations were as follows:

At the beginning of each day/line:

- An uncorrelated sweep was viewed either on the computer screen or on hardcopy. This provided a check to ensure that the vibrator was operating properly, and that the RTS-100 trigger boxes triggered the seismograph correctly.
- Check array parameters (i.e., source location, sweep configuration, receiver spacing, etc.) and connections.
- Check the noise monitor on the seismographs to identify any ambient noise problems and to isolate and correct any noisy or dead receiver channels. The noise monitor was also useful for confirming the correct setting on the roll box by lightly tapping the first and last active phone.

Line production included:

- Starting each line with the source located at the first geophone station on the line, (the first shot would have 144 channels live in front of the vibrator);
- Keeping the roll box in the initial position, the Minivib would "roll" into the spread, until there were 72 live channels on both sides;
- With a split spread, the roll box would be incremented by one on each shot, keeping the vibrator at the center of the active spread until reaching the last live channel; and
- Once the last live channel was reached, the vibrator would "roll" off the spread, in the reverse process to the start of the line. On the last shot, the Minivib would be at the last station, resulting in 144 live channels behind the vibrator on the last shot.

After each cable at the beginning (low side) of the spread became inactive, the cable and geophones were advanced to the next cable position by the line crew (i.e., phones and cables occupying stations 1-48 would be moved to stations 217-264).

3.0 DATA PROCESSING

Site 3A p-wave seismic reflection data were processed using UNIX-based ProMax® software. The processing flow is based on a standard common midpoint (CMP) reflection processing sequence with modifications for specific conditions at the survey site. Each line was processed individually while keeping all area-based parameters the same for uniformity. **Table 3-1** below shows each step in the processing sequence leading to the final stacks used for interpretation.

TABLE 3-1
DATA PROCESSING FLOW

Sequence	Process Applied	Relevant Parameters
1	Data Reformat / Vibroseis Sweep Correlation	
2	Geometry Definition & Trace Edit	
3	Refraction Statics	Vc = 6000 ft/s; V0= 3000 ft/s; V1= 5239 ft/s
4	True Amplitude Gain Recovery	
5	Surface Consistent Amplitude Recovery	
6	Surface Consistent Spiking Decon	Operator: 60 msec; Noise 0.01%
7	Spectral Enhancement	30-320 Hz
8	CDP Gather	
9	Velocity / Mute Analysis	
10	NMO Correction and Mute Application	
11	Surface Consistent Auto Statics	40-240 msec Static Gate
12	Velocity / Mute Analysis - Pass 2	
13	NMO Correction and Mute Application - Pass 2	
14	Surface Consistent Auto Statics - Pass 2	50-250 msec Static Gate
15	Surface Consistent Residual Statics	
16	Linear Noise Suppression	
17	Time Variant Scaling	
18	CDP Trim Statics	1 msec Max. Static
19	CDP Stack	
20	Correction to Flat Datum	Datum: 500 feet; Vc = 6000 f/s
21	Spectral Whitening	30-300 Hz
22	F-X Predictive Filtering	
23	Bandpass Filter	50/18 - 200/72 Hz/dB
24	AGC Scaling	

Data processing includes compressing the frequency-modulated signal (Vibroseis correlation) to a signal similar to that observed with explosives or other impulsive seismic sources. The geometry and coordinates of all sources and receivers on the seismic profile are then input to the computer and bad data traces are edited out (geometry and trace edit). An attempt is made to reverse the localized filtering effects that near surface materials cause on the seismic signal (deconvolution and amplitude recovery).

Effects of surface topography and variations in the upper layers of the earth are applied to the data (datum, refraction, and automatic statics). Nonlinear effects of the data acquisition geometry (velocity analysis and normal moveout correction) are accounted for and removed in order to correctly image subsurface features. Directional filters are applied to the source (shot) records to eliminate unwanted signals generated by the seismic sources (FK filter). Statistical data sets are sorted and then summed by subsurface reflection point (common midpoint stack). The data are spectrally whitened to adjust amplitudes of all frequency components and filtered to keep those reflection frequencies with the best signal/noise ratio.

Good sources for explaining seismic data processing can be found in Seismic Exploration Fundamentals by Coffeen, 1978, and Seismic Data Processing by Yilmaz, 1997.

4.0 INTERPRETATION

Uninterpreted enhanced stacked sections are presented as **Figures 8A-14A** (variable density grayscale) and in **Appendix B** (variable area wiggle trace). Uninterpreted instantaneous phase seismic sections are presented as **Figures 8B-14B**. Interpreted instantaneous phase seismic sections are presented as **Figures 8C-14C**. A map view of these interpretations is presented in **Figure 15**. In addition to the geophysical interpretation, the seismic interpretation map contains detailed information on reference features (e.g., roads, utility corridors, and fences), so that the survey lines and seismic anomaly locations can be relocated in the future.

4.1 SEISMIC FORWARD MODELING AND DEPTH CORRELATION

Seismic forward modeling was performed using the Green Mountain GRIP® software. Modeling was conducted prior to data interpretation for two reasons. First, forward modeling provided an estimate of two-way travel time anomalies that would be generated by various vertical displacements along the bedrock surface. Second, forward modeling was used in an attempt to verify reflections seen at specific two-way travel times in the seismic sections were associated with known depths to the top of the Porters Creek Clay Formation, the McNairy Formation, or top of limestone bedrock.

Another approach for providing a time to depth correlation is to use sonic log data from a nearby well to generate a synthetic seismogram. However, at the time of this writing, a sonic log was not available. Like all seismic data that is not calibrated to well control, the phase of the Site 3A data is unknown. Theoretically, the raw data is zero-phase, but it is difficult to say what has happened to the phase of the data during processing. The data is often mixed-phase after deconvolution, and until a sonic log is acquired in a well located along or near one of these lines, the phase cannot be known for sure. If a seismic log becomes available in the future, additional analysis of these seismic data may better pinpoint or characterize the anomalies identified, but are not likely to change the basic conclusions.

The seismic forward modeling diagram **(Figure 7)** shows the input model velocities and material densities for a 4-layer case representing subsurface conditions at Site 3A. Synthetic reflections representing the top of the Porters Creek Clay, top of McNairy, and top of bedrock occur at approximately 20, 100, and 200 msec, respectively. These values are generally consistent with those observed in the Site 3A seismic data. Seismic modeling for the purposes of estimating vertical displacements is limited to offsets in bedrock only and does not include diffraction patterns that would be generated by the vertical displacement. As shown in **Figure 7**, vertical offsets at the top of bedrock on the order of 2, 5, and 10 feet would be expected to generate two-way travel time anomalies in the seismic data of approximately 1.5, 3.0, and 6.0 msec, respectively.

4.2 INTERPRETATION METHOD

Site 3A seismic reflection data were analyzed using a seismic workstation and the instantaneous phase display capabilities of Geophysical Microcomputer Applications (GMA®) 2D/3D software. The instantaneous phase type of complex trace analysis is well suited for detecting faults for the following reasons:

- Emphasizes the spatial continuity / discontinuity of reflections;
- Makes weak coherent events clearer;
- Effective at highlighting discontinuities, faults, pinch-outs, angularities, and bed interfaces;
- Propagating sedimentary layer patterns and regions of onlap and offlap layering often show with extra clarity; and

- Good for picking seismic sequence boundaries.

The workstation has the capability to perform the following functions on processed seismic data in digital format:

- Filtering;
- Color display of seismic data;
- Attribute calculation;
- Digital picking (logging) of seismic event travel times;
- Fault tracking; and
- Gain functions.

The workstation analysis consisted of applying various filters to determine optimum signal bandwidth, calculation of seismic attributes (e.g., amplitude envelope, trace amplitude, instantaneous phase), and viewing the data in different color schemes to identify reflections of interest.

Prior to final analysis, the seismic data were converted to instantaneous phase sections. When considered as an analytic signal, seismic traces can be expressed as a complex function, where the real part is the recorded seismic signal and the imaginary part is the quadrature, which is simply the 90-degree phase shifted version of the real part (Yilmaz 1997). The instantaneous phase is a measure of the continuity of events on a seismic line and indicates the sample-by-sample ratio of the quadrature and seismic traces.

Expressed mathematically, the instantaneous phase is:

Arctan [q(t) / r(t)]

where, q(t) = quadrature phase or Hilbert transform of the real part,
r(t) = real part or recorded seismic signal.

The approach to interpreting the Site 3A seismic data included the following:

- Identifying key seismic horizons, such as the top of the McNairy Formation and the top of limestone bedrock;

- Analyzing the instantaneous phase sections for significant diffractions and/or termination of reflections typical of faulting;

- Analyzing anomaly "signature" and geometry characteristics along each line for features, such as abrupt vertical offsets, dip orientations, and lateral changes in reflection character over a range of reflection times in the seismic section;

- Correlating interpreted faults along specific lines to other Site 3A lines to determine potential linear relationships between anomalies; and

- Estimating the direction of dip and relative movement along fault planes.

Diffraction analysis was performed on the data to identify diffractions in each data set. Diffraction is the bending of wave energy around an obstacle as the wave propagates past the obstacle. Diffractions appear on a seismic section as an inverted hyperbola. The curvature of the hyperbola is dependent on the propagation velocity of acoustic energy from the surface to the object causing the diffraction. Generally, diffractions are generated at any termination of a lateral reflection surface or by objects that are too small to be otherwise imaged.

Diffraction analysis provides an excellent means of identifying faults where vertical offsets are very small because terminating reflections typically generate a diffraction for each reflective surface that was interrupted by the fault. Multiple diffractions can be identified and the apexes of the diffractions can be connected to identify the location of the fault. Generally, diffractions are identifiable on noisy data where the continuity of subsurface reflections has been mitigated by noise.

In addition to diffraction analysis, the coherency of individual reflectors was reviewed for vertical displacements and/or geometry characteristics potentially caused by faulting.

Seismic data analysis results are shown on the interpreted instantaneous phase sections **(Figures 8-14)** and the seismic interpretation map **(Figure 15)**. Color amplitude scales and horizontal / vertical scales for the data were selected to enhance features of interest and kept constant for comparison between sections.

4.3 GENERAL CHARACTERISTICS

The seismic data quality from 6 of the 7 survey lines was generally good and the results are reasonable with site conditions and known geologic materials documented in a nearby boring log. Line 2 data quality, particularly along the eastern half of the line, was marginal due seismic coupling problems in the wet / muddy soil.

Line intersection and tie-points are shown in **Table 4-1**. With the exception of a small mistie at the low-fold intersection of Lines 1B and 3, the time-ties between lines are good.

TABLE 4-1

SEISMIC LINE INTERSECTIONS AND TIME-TIES

Line	Station	Line	Station	Northing	Easting	Time Tie *
1A	141.1	4	583.9	-4788.27	-5959.71	-1
1B	319	3	1014.2	-1136.72	-5969.44	-5 (Low Fold Area)
2	747.5	3	811.5	-1908.46	-6700.91	0
2	163.7	4	433.8	-4784.50	-6714.81	0
2	462.1	5A	280.7	-3279.47	-6720.36	1
3	168.7	4	176	-4779.75	-8000.17	0
3	550.1	5A	149.5	-3017.20	-7280.05	-1

*In milliseconds. A positive time-tie indicates that a reflection on the intersecting line (column 3) is delayed (it arrives later in time) with respect to the corresponding reflection on the line being tied (column 1), by the time in the Time-Tie column. Likewise, a negative time-tie indicates reflections on the intersecting line arriving earlier than the corresponding reflection on the line being tied.

The dominant features on all seismic sections **(Figures 8-14)** are a group of strong reflectors ranging from approximately 70 to 190 msec. Based on expected p-wave velocities for the sediments (~2,500 to 4,000 ft/s) and for the limestone (~15,500 ft/s) shown in **Figure 7**, two of these reflectors appear to coincide with events originating from at or near the top of the McNairy Formation and the top of the limestone bedrock. Reflections from the top of the McNairy and top of limestone are indicated on interpreted seismic sections by red and yellow shading, respectively. Although discontinuous in many portions of the survey lines and above the target zone for this investigation, reflections can also be seen from what is thought to be the top of the Porters Creek Clay Formation ranging from ~30 to perhaps 60 msec. Although not a serious concern at Site 3A because velocities generally increase with depth, some portions of the seismic lines may contain multiples. This "ringing" occurs when a high impedence contrast causes the wave energy to be trapped in the sedimentary section. The raypaths that produce these multiples are illustrated in **Figure 6**.

Other dominant features that are more of interest to this investigation include the numerous breaks in the lateral continuity of some reflectors and numerous diffraction patterns that are particularly evident in the limestone bedrock. Anomalies in reflector coherency can be seen in the wiggle-trace uninterpreted sections **(Appendix B)** and the interpreted instantaneous phase sections; however, anomalies associated with diffractions are most evident in the instantaneous phase sections.

Based on the seismic data acquired at Site 3A, eleven faults have been interpreted to trend generally north-northeast (NNE) through the site **(Figure 15)**.

4.4 LINE-BY-LINE INTERPRETATIONS

Line 1A

Line 1A trends east to west (E-W) along the northwestern part of the site. Faults, identified as 1 through 3, were interpreted on the Line 1A seismic section **(Figure 8C)**. All three features are interpreted to dip toward the east and to extend from the Paleozoic limestone basement up through the top of the McNairy. Relative movement along each interpreted fault is down on the east. Based on the physical characteristics of each anomaly identified, the faults are interpreted to trend NNE and intersect Lines 2, 3, and 4 at the locations identified on the seismic interpretation map **(Figure 15)**. Although anomalous reflections are evident above approximately 60 msec (i.e., near the top of the Porters Creek Clay), particularly at Faults 1 and 3, correlations could not be determined with any degree of certainty.

Line 1B

Line 1B trends E-W along the northwestern part of the site and essentially represents the eastward extension of Line 1A east of the C-745-T Cylinder Yard. Faults, identified as 9 through 11, were interpreted on the Line 1B seismic section **(Figure 9C)**. All three features are interpreted to dip toward the east and to extend up through the Paleozoic limestone basement. Fault 11 is interpreted to offset the top of the McNairy and possibly extend up into the Porters Creek Clay. Horst and graben type relative movement is interpreted along these faults, with the blocks west of Fault 9 and between Faults 10 and 11 being horsts and the blocks between Faults 9 and 10 and east of Fault 11 being grabens. Based on the physical characteristics of each anomaly identified, the faults are interpreted to trend NNE and intersect Lines 2 and 3 at the locations identified on the seismic interpretation map. Anomalous reflections are evident above approximately 70 msec (i.e., near the top of the Porters Creek Clay), particularly at Fault 11.

Line 2

Line 2 trends E-W in the central portion of the site and along the overhead utility corridor. Line 2 data represents the poorest quality observed in the Site 3A data set, likely due to seismic coupling problems associated with wet and muddy surfaces conditions. Faults, identified as 2 through 10, were interpreted on the Line 2 seismic section **(Figure 10C)**, although some along the eastern half of the line should be viewed as questionable. All features are interpreted to dip toward the east and to extend up through the Paleozoic limestone basement. Faults 3, 4, 6, 7, and 8 are interpreted to offset the top of the

McNairy, with Faults 3, 4 and 6 possibly extending well into or through the Porters Creek Clay. Between Faults 4 and 6 (~stations 405 to 505), a significant anticline-type feature is evident as an approximately 10 to 15 msec pull-up in the data. This feature is interpreted to broaden toward the SSW where it intersects Line 3. Relative movement along faults blocks evident in the Line 2 data may best be described as complex, with generally horst and graben structures along the eastern portion of the line and a series of westward rotated blocks along the western portion of the line. Based on the physical characteristics of each anomaly identified, the faults are interpreted to trend NNE and intersect Lines 1A, 1B, 3, 4, and 5A at the locations identified on **Figure 15**.

Line 3

Line 3 trends southwest to northeast (SW-NE) along Dyke Road and represents the southern boundary of the area investigated. Faults, identified as 3 through 11, were interpreted on the Line 3 seismic section **(Figure 11C)**. All features are interpreted to dip toward the east and to extend up through the Paleozoic limestone basement. Features 3 through 5 may include antithetic faults or be associated with flower structures. Faults 4, 6, 7, 8, and 10 are interpreted to offset the top of the McNairy and possibly extend upward well into or through the Porters Creek Clay. Between Faults 4 and 6 (~stations 270 to 530), a significant anticline-type feature is evident as an approximately 10 to 15 msec pull-up in the data. This feature is interpreted to narrow toward the NNE where it intersects Line 2. Within the block between Faults 4 and 5, reflections representing the top of bedrock are high amplitude, but discontinuous, which differs from the relatively coherent reflections from bedrock along most other portions of the line. These characteristics combined with multiple strong diffractions evident beneath the bedrock reflection indicate a significant fault / fracture zone may exist at this location. Similar to Line 2, relative movement along faults blocks seen in the Line 3 data is complex, with generally horst and graben structures along the eastern half of the line and a series of westward rotated blocks along the western half of the line. Based on the physical characteristics of each anomaly identified, the faults are interpreted to trend NNE and intersect Lines 1A, 1B, 2, 4, and 5A at the locations identified on **Figure 15**.

Line 4

Line 4 trends north to south (N-S) along the eastern side of a frontage road adjacent to Hobbs Road, and represents the western boundary of the area investigated. Faults, identified as 1 through 3, were interpreted on the Line 4 seismic section **(Figure 12C)**. All features are interpreted to dip toward the south and to extend up through the Paleozoic limestone basement. Feature 2 may represent a series of en echelon or antithetic faults associated with a horst and graben complex. The northernmost component of Fault 2 and Fault 1 are interpreted to offset the top of the McNairy and possibly extend upward into the Porters Creek Clay. Along the southernmost component of Fault 2 (~stations 280 to 340), a significant discontinuity in the bedrock reflector exists. The character of this reflector combined with multiple strong diffractions evident beneath the reflector indicates a significant fault / fracture zone may exist at this location. Based on the physical characteristics of each anomaly identified, the faults are interpreted to trend NNE and intersect Lines 1A and 2 at the locations identified on the seismic interpretation map.

Line 5A

Line 5A trends southeast to northwest (SE-NW) along a gravel road through the central portion of the site. Faults, identified as 4 through 6, were interpreted on the Line 5A seismic section **(Figure 13C)**. All features are interpreted to dip toward the south and to extend up through the Paleozoic limestone basement. Fault 6 is interpreted to offset the top of the McNairy and possibly extend upward into the Porters Creek Clay. Based on the physical characteristics of each anomaly identified, the faults are interpreted to trend NNE and intersect Lines 2 and 3 at the locations identified on **Figure 15**.

Line 5B

Line 5B trends S-N through the central portion of the site and along the western side of the C-745-T Cylinder Yard. No faults were interpreted in the Line 5B data **(Figure 14C)**, probably because the orientation of Line 5B is sub-parallel to the strike of the faults mapped along other lines at Site 3A.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The p-wave seismic reflection survey was successful in imaging several horizons beneath Site 3A, including the top of limestone bedrock, top of the McNairy, and portions of the Porters Creek Clay. A total of eleven north-northeast trending faults have been interpreted in the data. Fault orientations were determined by correlating significant discontinuities along reflectors and similar diffraction patterns between seismic survey lines.

Relative movement along the interpreted fault blocks throughout Site 3A appears to be complex, with generally horst and graben structures in the eastern portion of the survey area, and blocks that have rotated, or dip, toward the west in the western portion of site. The overall trend and geometry of the faulting in bedrock is generally similar to faulting observed in the Fluorspar Area Fault Complex of Massac County, Illinois, located just across the Ohio River.

All eleven interpreted faults show disruptions near the top of the bedrock limestone that appear to offset that unit. Nine of the eleven faults are interpreted to extend upward into the Cretaceous-age McNairy Formation. Several of these features may extend well into or possibly through the Paleocene-age Porters Creek Clay Formation. Further analysis of this Site 3A seismic data may refine the anomalies identified, but are not likely to change these basic conclusions.

It is important to stress that this p-wave reflection survey does not have sufficient resolution to unequivocally determine if the postulated faulting extends into the gravel deposits, fine-grained continental deposits, and/or Quaternary aged loess that are thought to overlie the Porters Creek Clay. This will require a more focused, s-wave seismic reflection study that targets the very shallow sediments located immediately above these interpreted faults as well as the analysis of soil borings and/or the collection of direct push samples.

6.0 CERTIFICATION

All geophysical data analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by Blackhawk GeoServices senior geophysicists.

Jeffrey B. Hackworth FOR STEVE HODGES 3/8/02

Steffan M. Hodges
Manager of Seismic Services
Blackhawk GeoSciences
Golden, Colorado

Date

Jeffrey B. Hackworth 3/8/02

Jeffrey B. Hackworth
California Registered Geophysicist GP979
Manager, Blackhawk GeoServices, Southeast Region
Oak Ridge, Tennessee

Date

* This geophysical investigation was conducted using sound scientific principles and state-of-the-art technology. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing, interpretation, and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review.

A geophysicist's certification of interpreted geophysical conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations, or ordinances.

7.0 REFERENCES

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Nelson W.J., F. B. Denny, L. R. Follmer, and J.M. Masters, 1998, "Quaternary grabens in southernmost Illinois: deformation near an active intraplate seismic zone," *Journal of Tectonophysics No. 305*, 1999, pp 381-397.

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Yilmaz, O., 1997, Seismic Data Processing, Society of Exploration Geophysicists.

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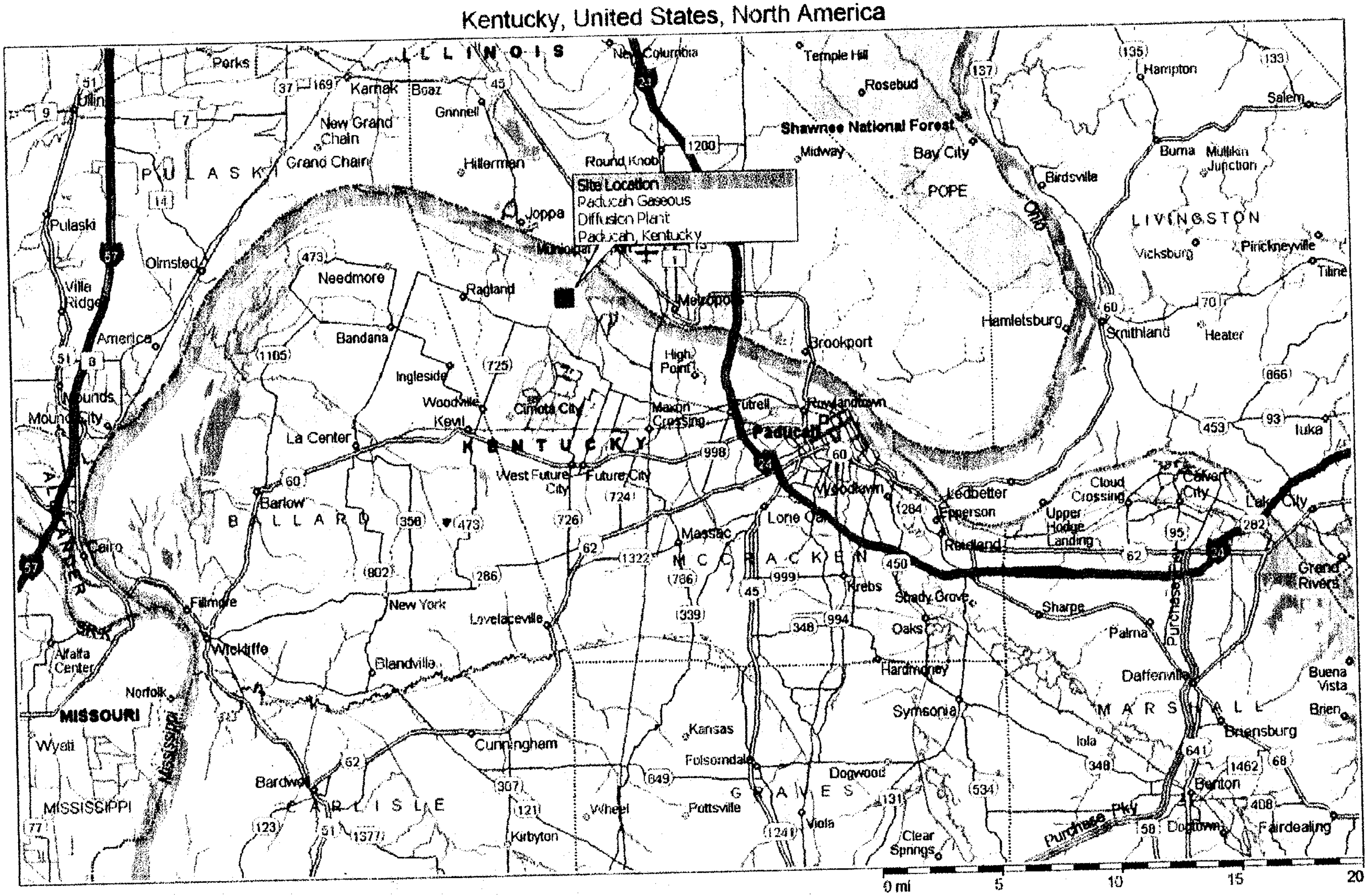
Kentucky, United States, North America



Site Location Map

Paducah Gaseous Diffusion Plant

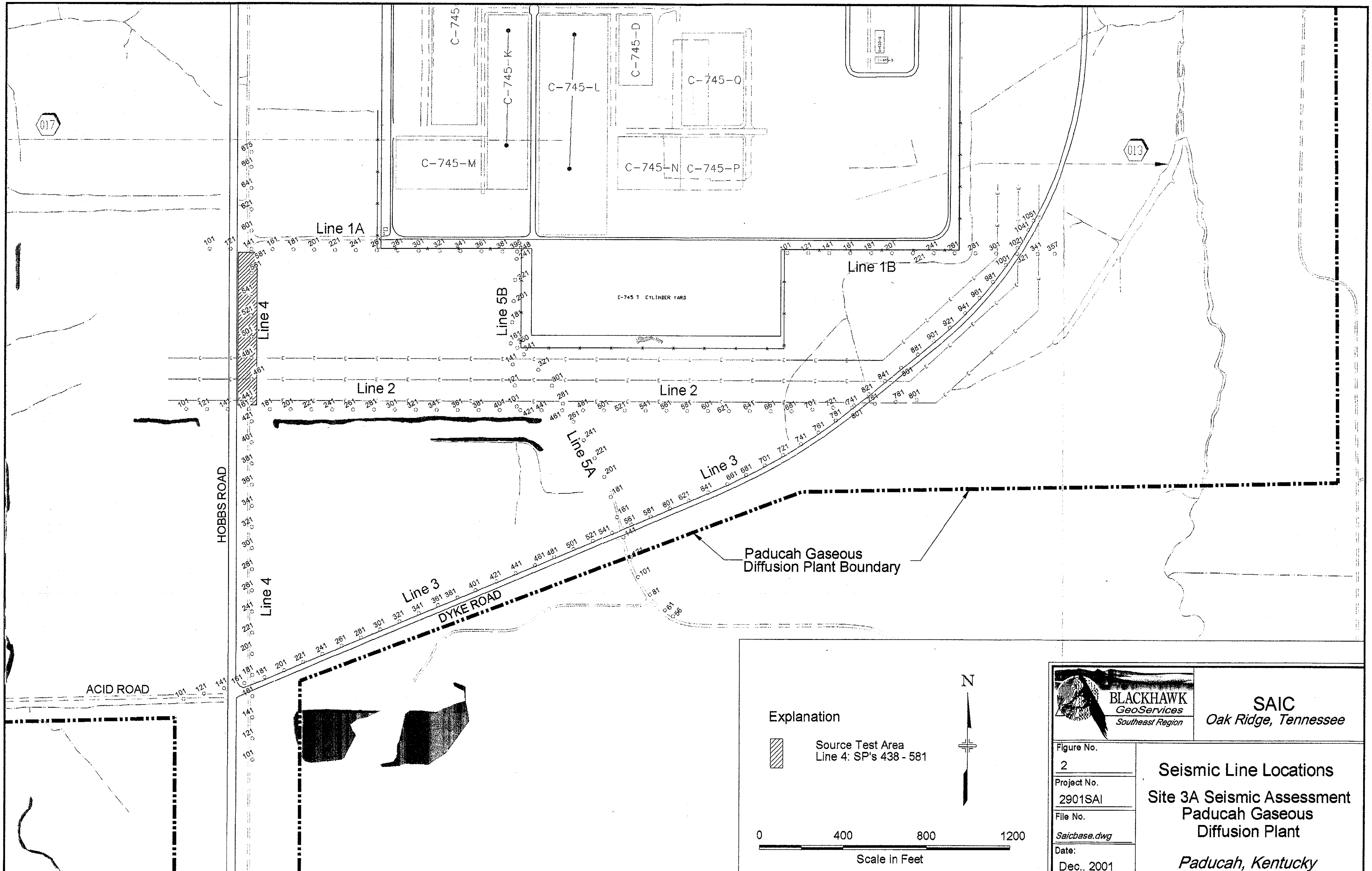
Paducah, Kentucky

BLACKHAWK *GeoServices* *Southeast Region*

Figure: 1

Project: 2901SAI

\projects\2901sai\SiteMap.cdr



BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 2

Project No. 2901SAI

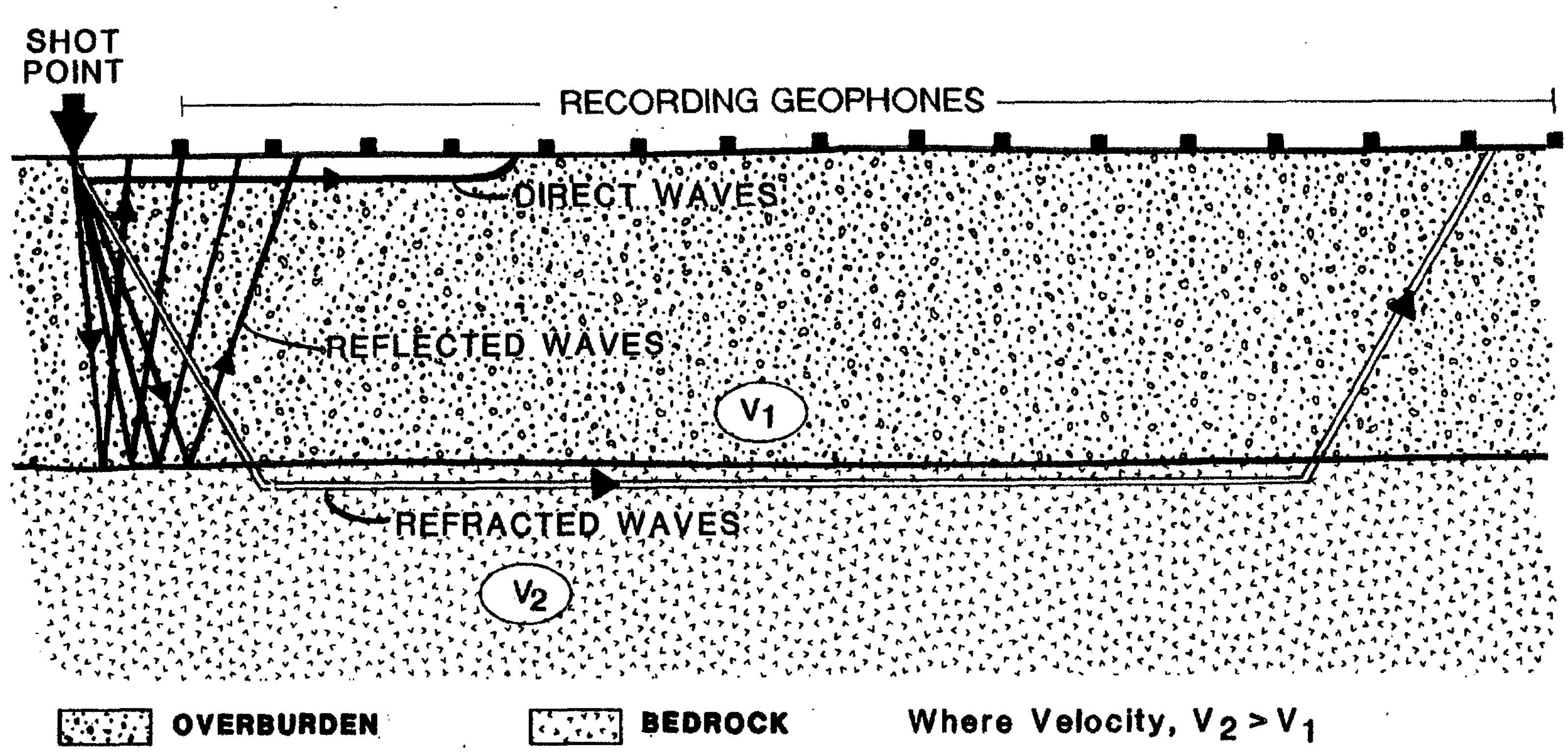
File No. Saicbase.dwg

Date: Dec., 2001

Seismic Line Locations

Site 3A Seismic Assessment
Paducah Gaseous
Diffusion Plant

Paducah, Kentucky



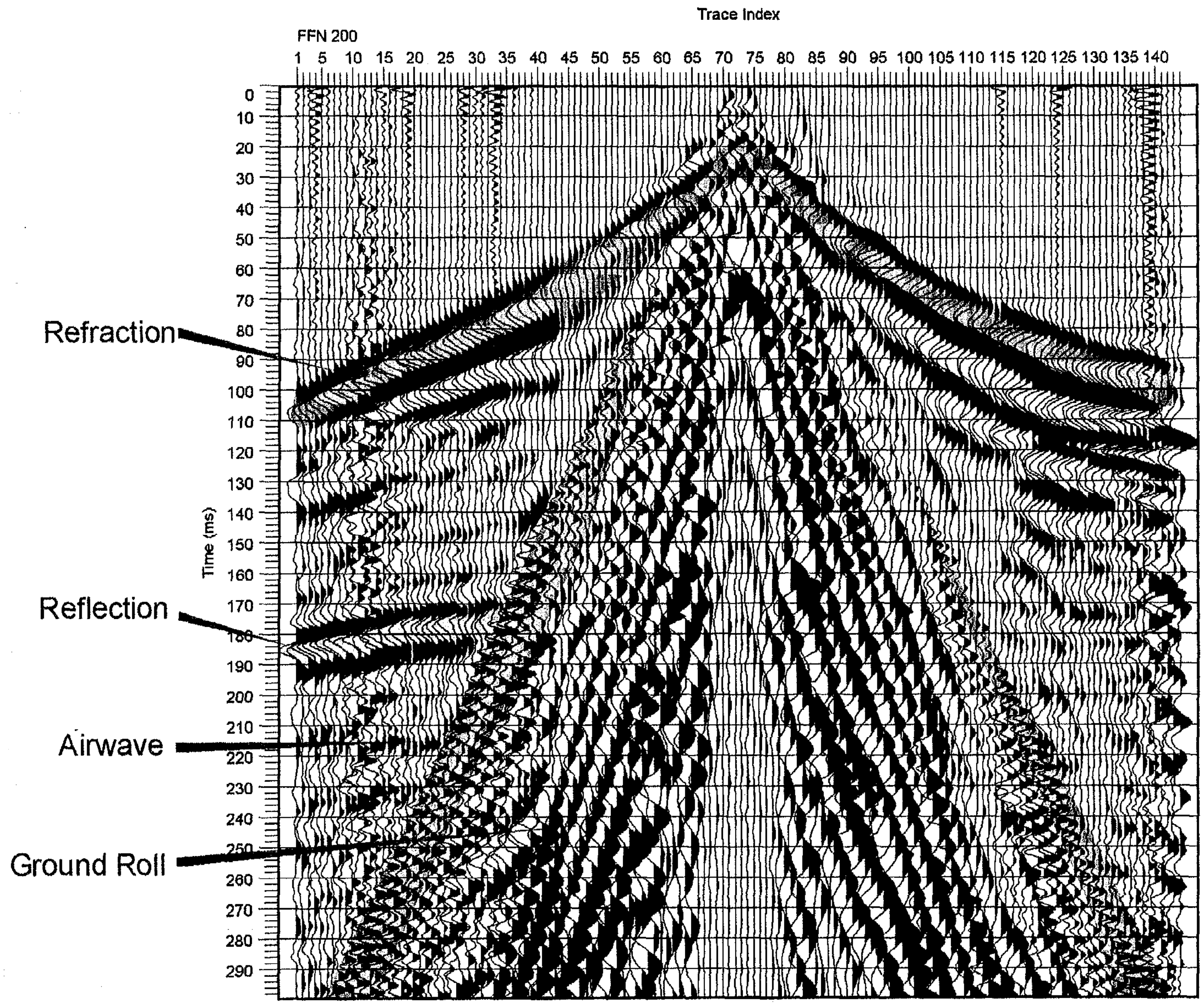
BLACKHAWK GeoServices Southeast Region

Seismic Raypath Geometry

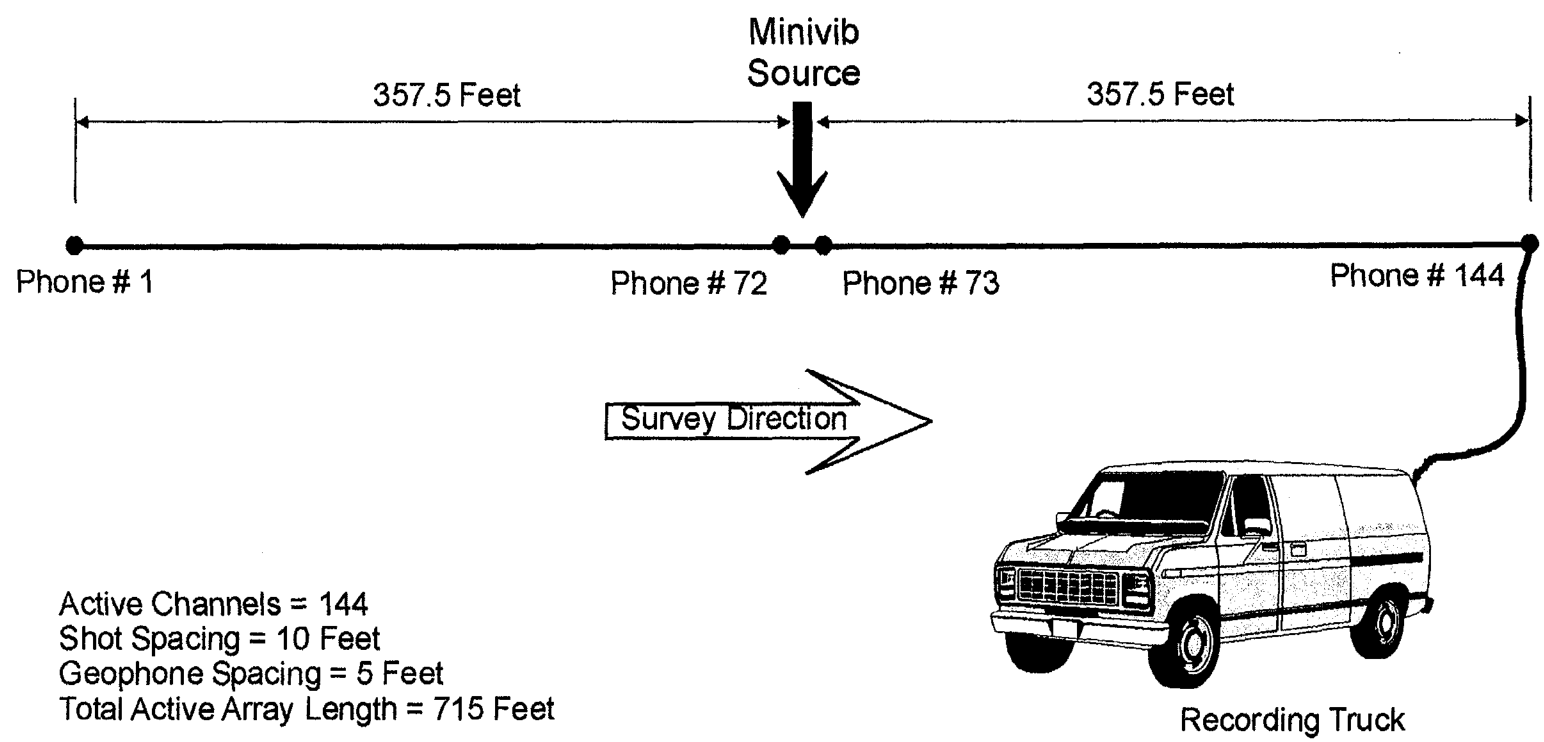
Figure: 3

Project: 2901SAI

|projects\2901sai\Raypath.cdr



BLACKHAWK *GeoServices* *Southeast Region*	**Sample Shot Record** (Line 3, FFID 200) *Paducah Gaseous Diffusion Plant* *Paducah, Kentucky*	Figure: 4 Project: 2901SAI \projects\2901sai\Shot_Record.cdr



Active Channels = 144
Shot Spacing = 10 Feet
Geophone Spacing = 5 Feet
Total Active Array Length = 715 Feet

BLACKHAWK GeoServices Southeast Region

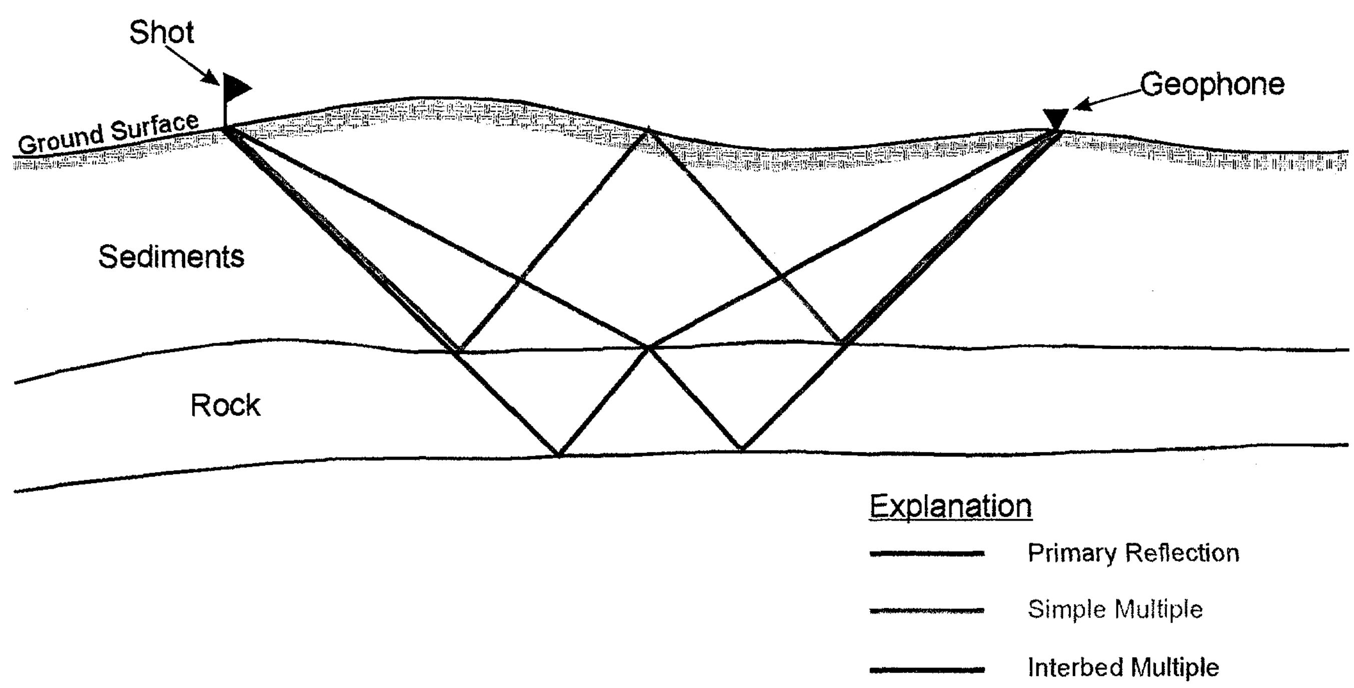
Diagram of Nominal Acquisition Geometry

Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Figure: 5

Project: 2901SAI

|projects\2901sai\SpreadReflec.cdr



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Southeast Region

Raypaths of Simple and Interbedded Multiples in the Seismic Reflection Data

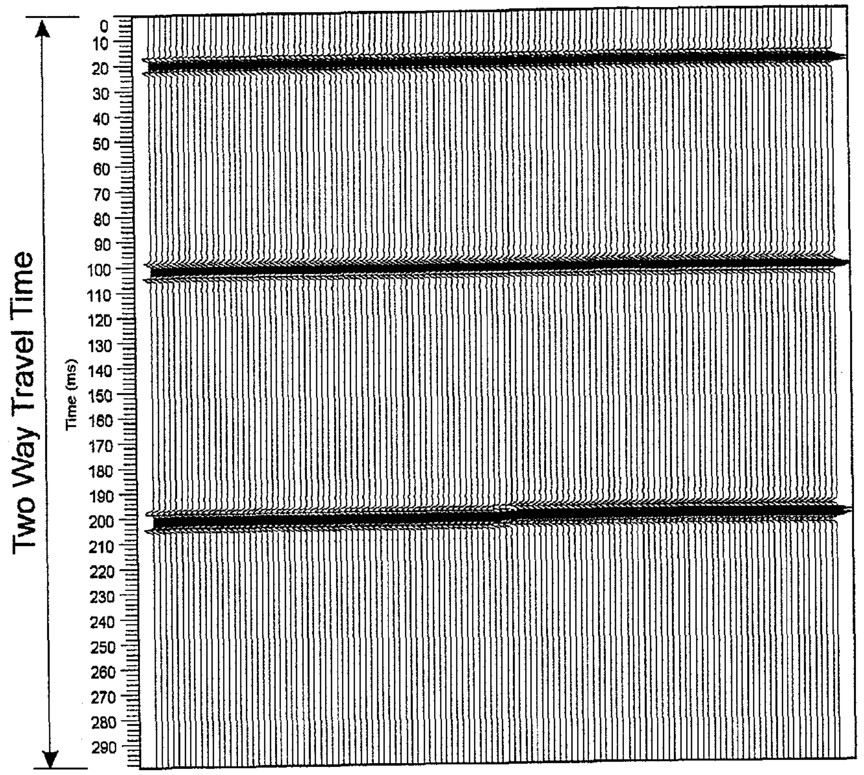
Paducah Gaseous Diffusion Plant

Paducah, Kentucky

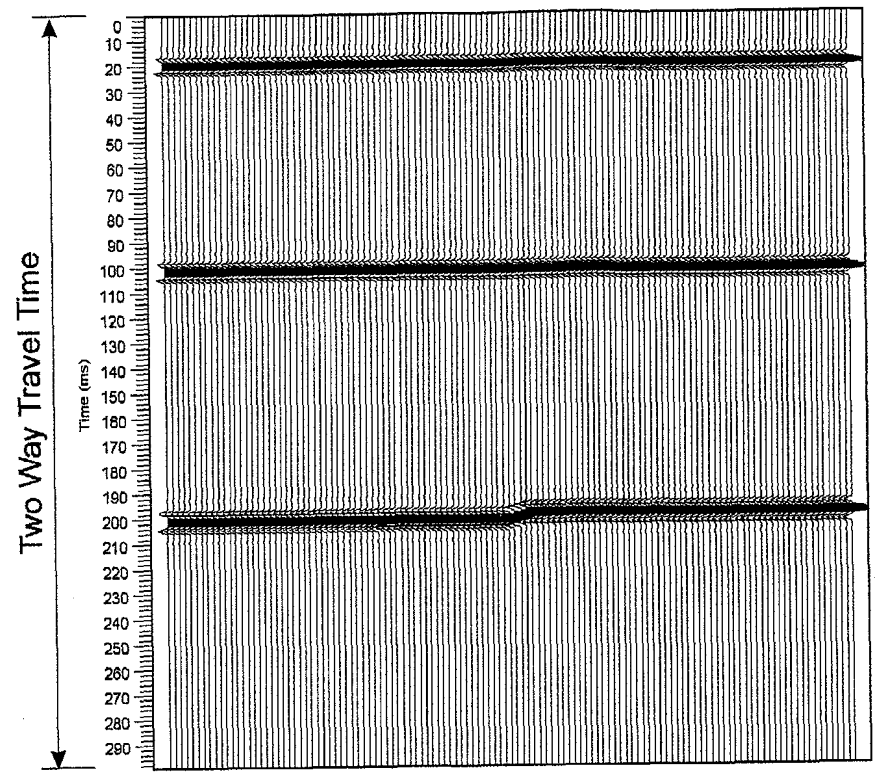
Figure: 6

Project: 2901SAI

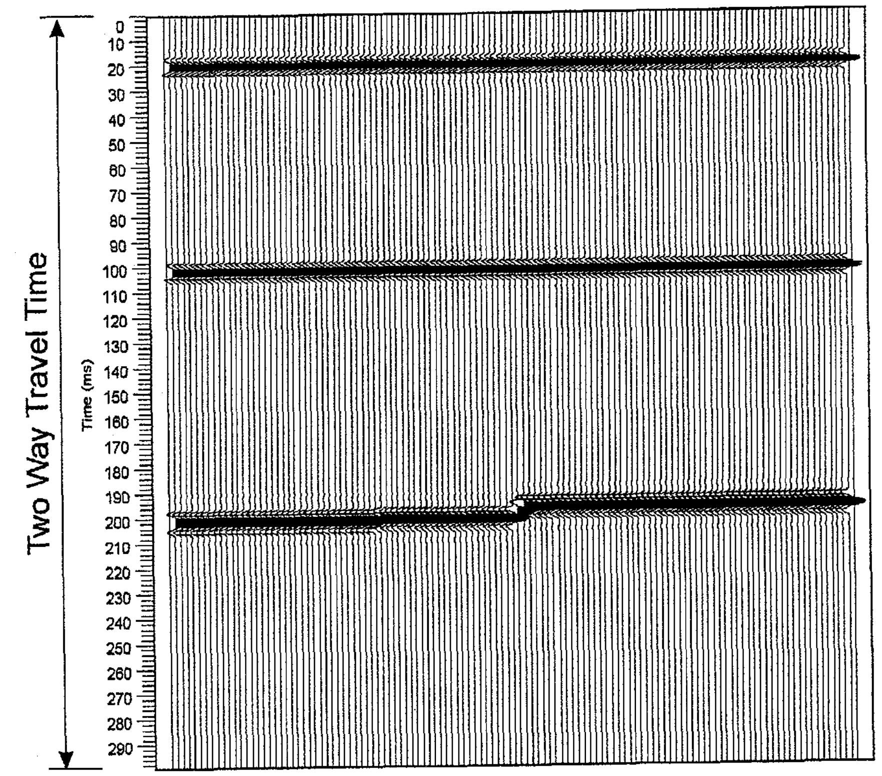
|projects\2901sai\Spreads.cdr



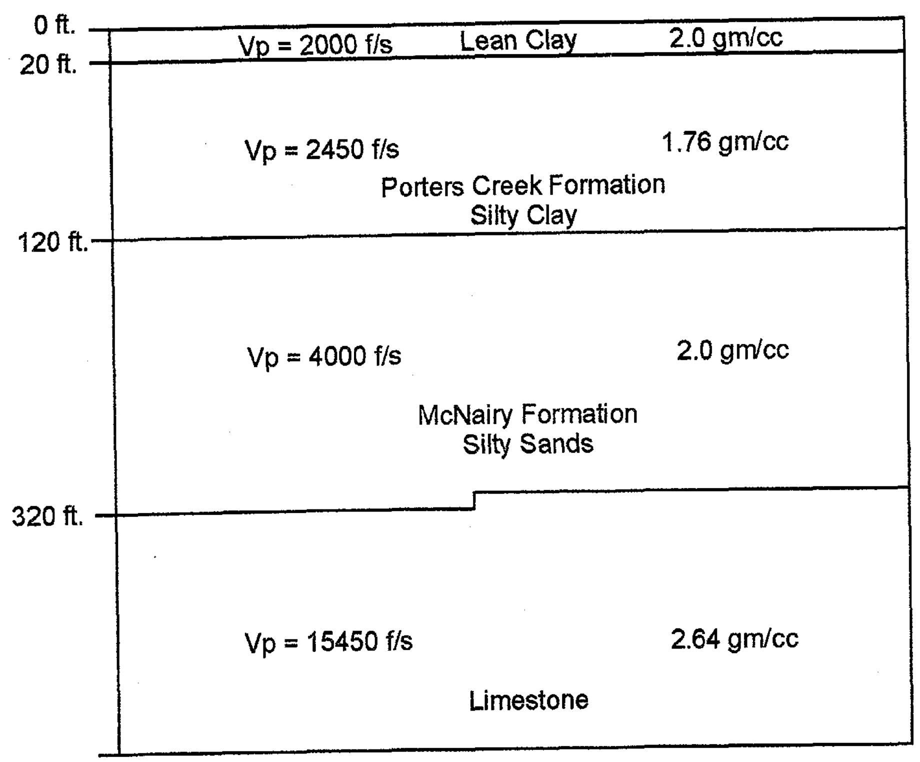
Fault in Limestone with 2 Ft. Vertical Displacement



Fault in Limestone with 5 Ft. Vertical Displacement



Fault in Limestone with 10 Ft. Vertical Displacement



Input Model

Model Extent
600 ft.

Group Interval
5 ft.

Shot Interval
10 ft.

Offset (ft.)
357.5 - 2.5 - X - 2.5 - 357.5

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Figure No.
7

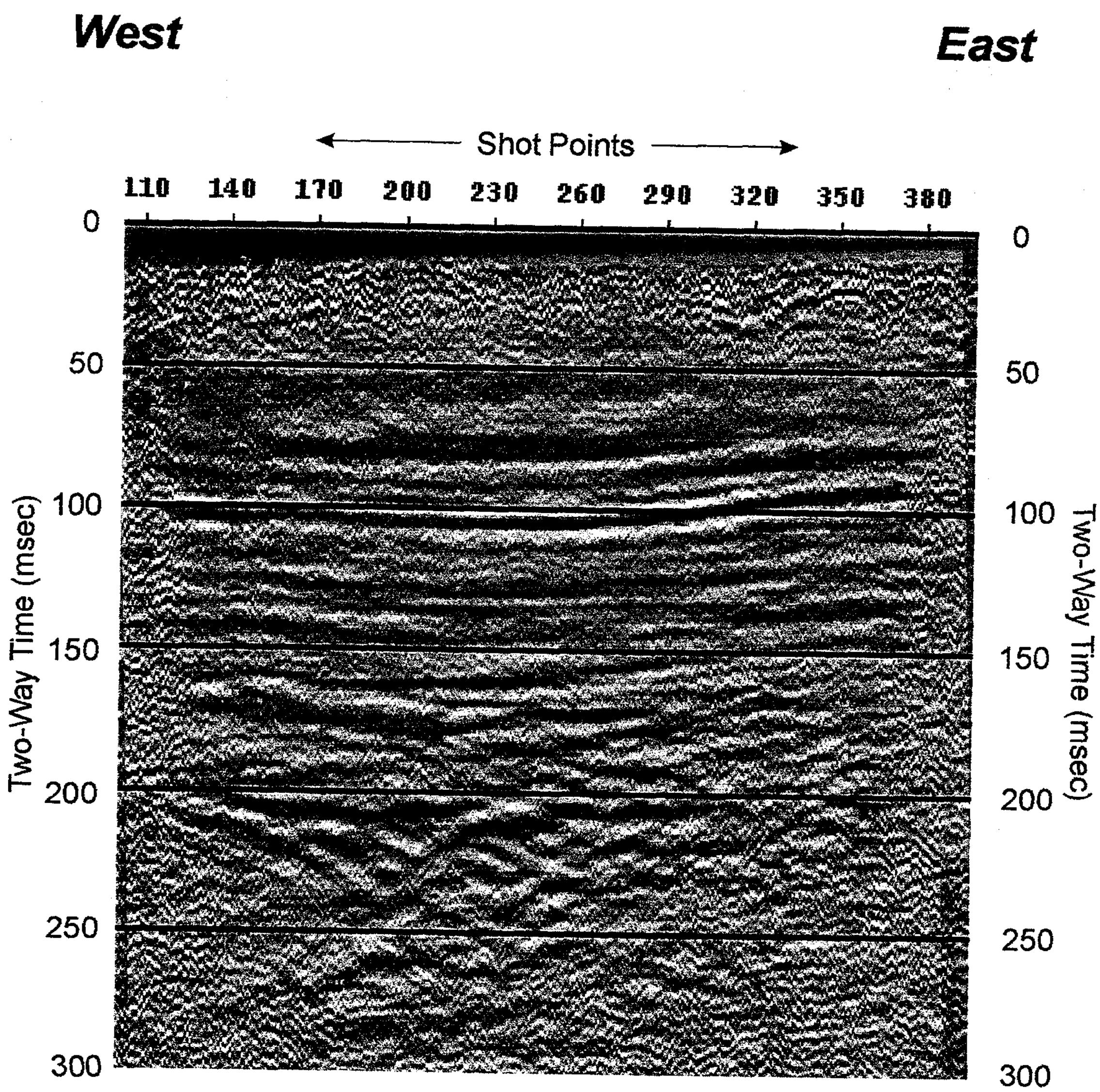
Project No.
2901SAI

File No.
2901sai\Models.cdr

Date:
Dec., 2001

Seismic Forward Modeling

Paducah Gaseous Diffusion Plant
Paducah, Kentucky



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Southeast Region

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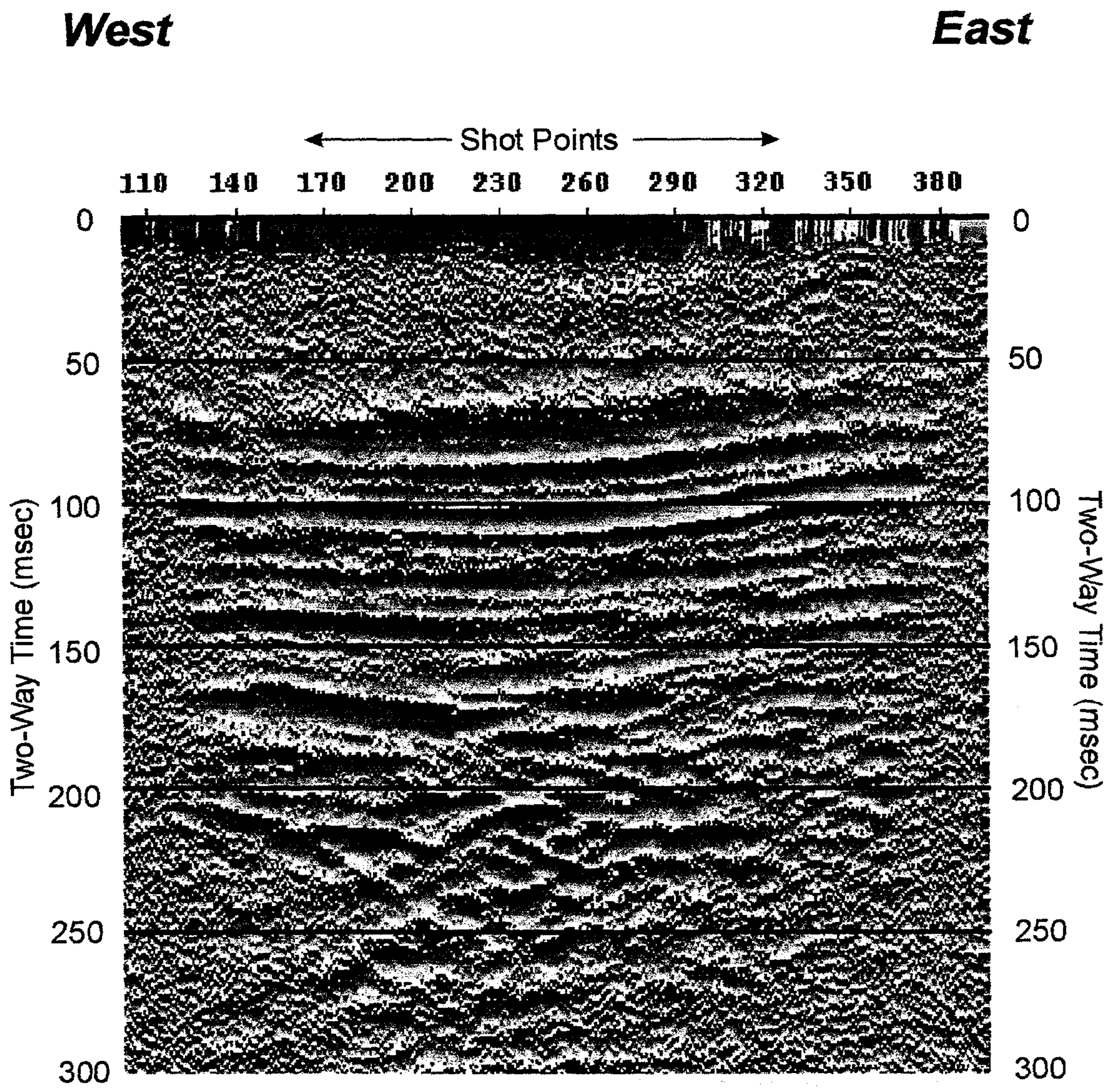
Oak Ridge, Tennessee

Figure No. 8A	**Line 1A**
Project No. 2901SAI	**Enhanced Stack (grayscale)**
File No. *2901saiGrayscale-1A.cdr*	*Paducah Gaseous Diffusion Plant*
Date: Dec., 2001	*Paducah, Kentucky*



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Oak Ridge, Tennessee

Figure No. 8B

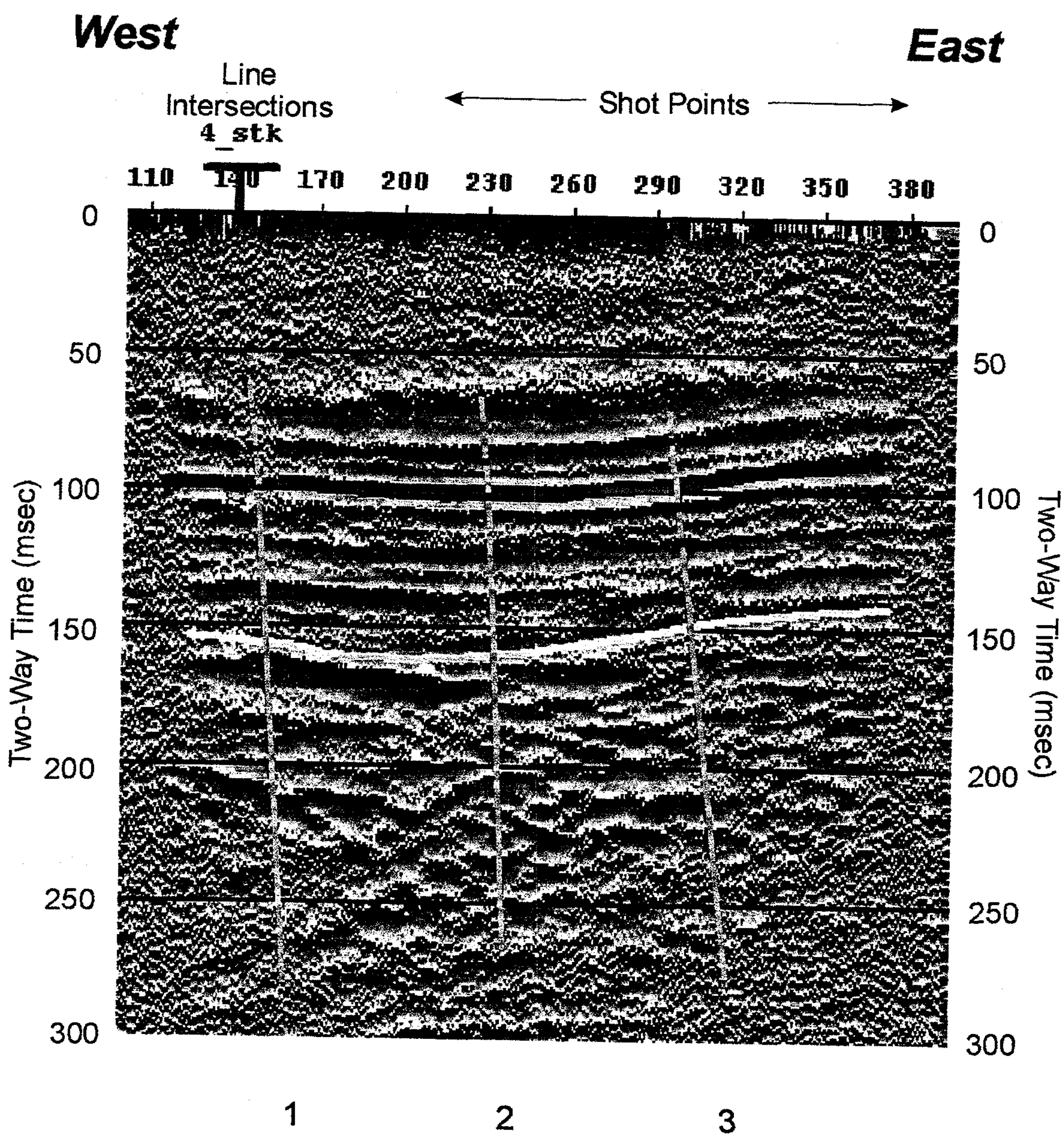
Project No. 2901SAI

File No. 2901sai\Uninterp1A.cdr

Date: Dec., 2001

Line 1A
Instantaneous Phase Section

Paducah Gaseous Diffusion Plant
Paducah, Kentucky



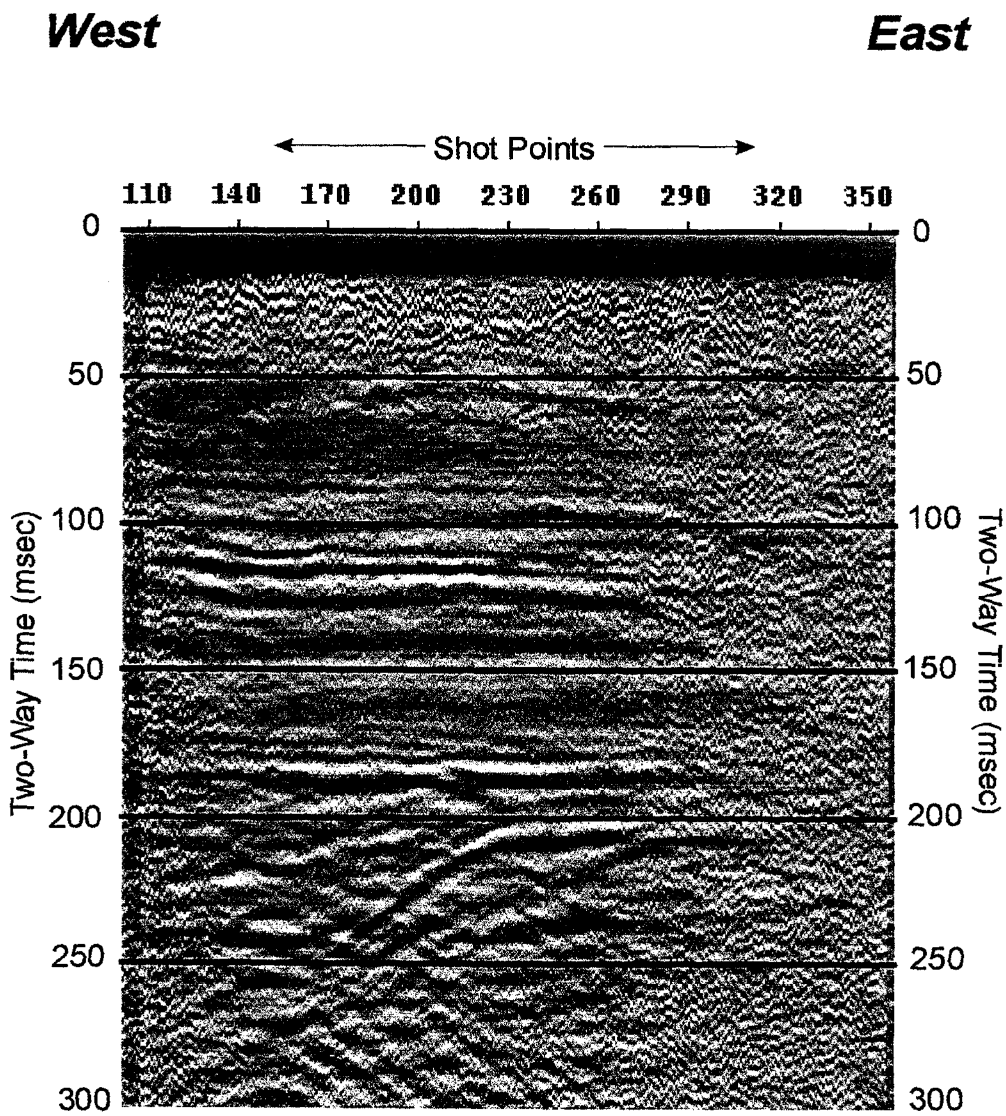
Explanation

Interpreted Top McNairy Formation

Interpreted Top Limestone

Interpreted Fault

BLACKHAWK GeoServices Southeast Region	SAIC Oak Ridge, Tennessee
Figure No. 8C	**Line 1A Interpreted Instantaneous Phase Section**
Project No. 2901SAI	
File No. *2901sai\Interp1A.cdr*	*Paducah Gaseous Diffusion Plant Paducah, Kentucky*
Date: Dec., 2001	



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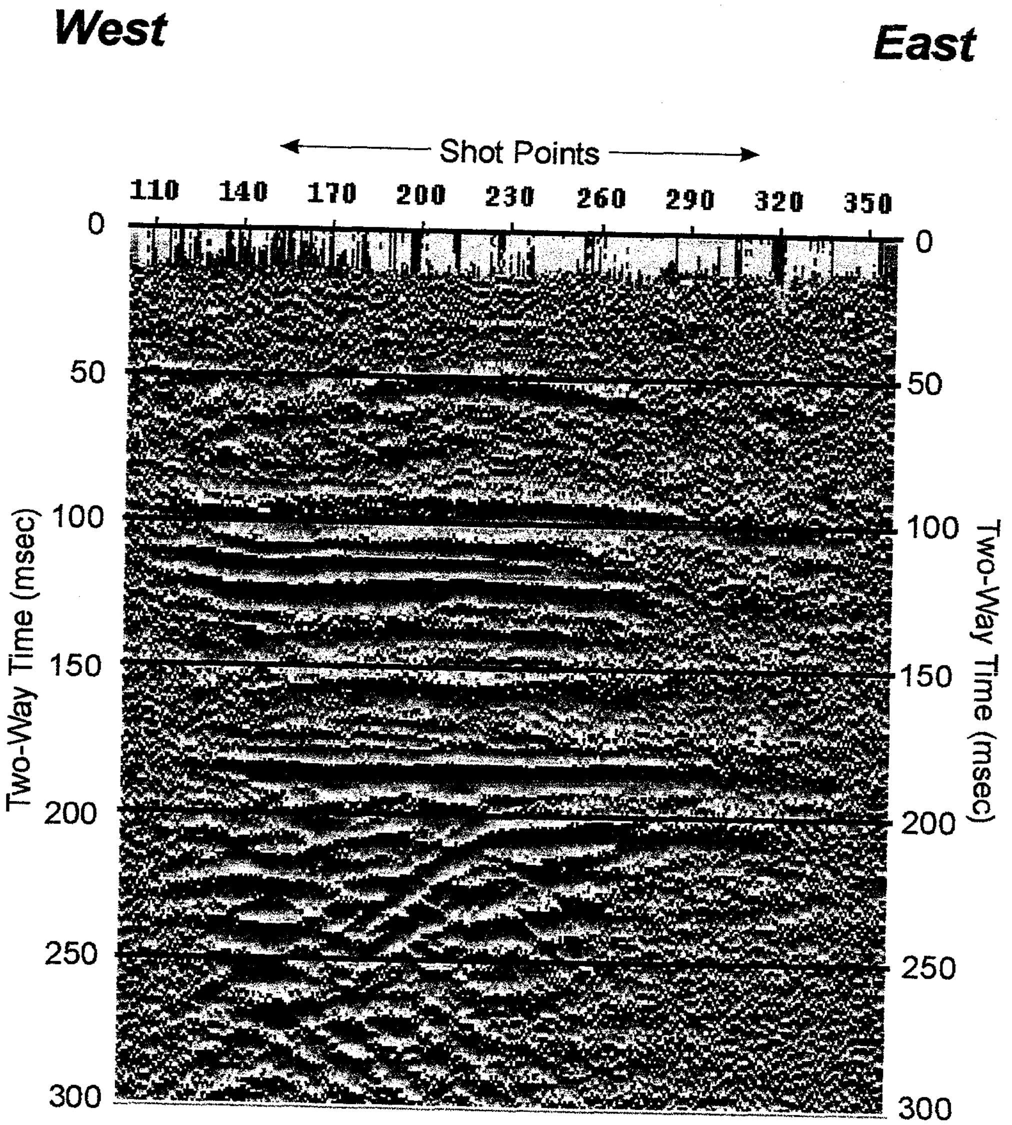
Oak Ridge, Tennessee

Figure No. 9A	**Line 1B**
Project No. 2901SAI	**Enhanced Stack (grayscale)**
File No. *2901saiGrayscale1B.cdr*	*Paducah Gaseous Diffusion Plant*
Date: Dec., 2001	*Paducah, Kentucky*



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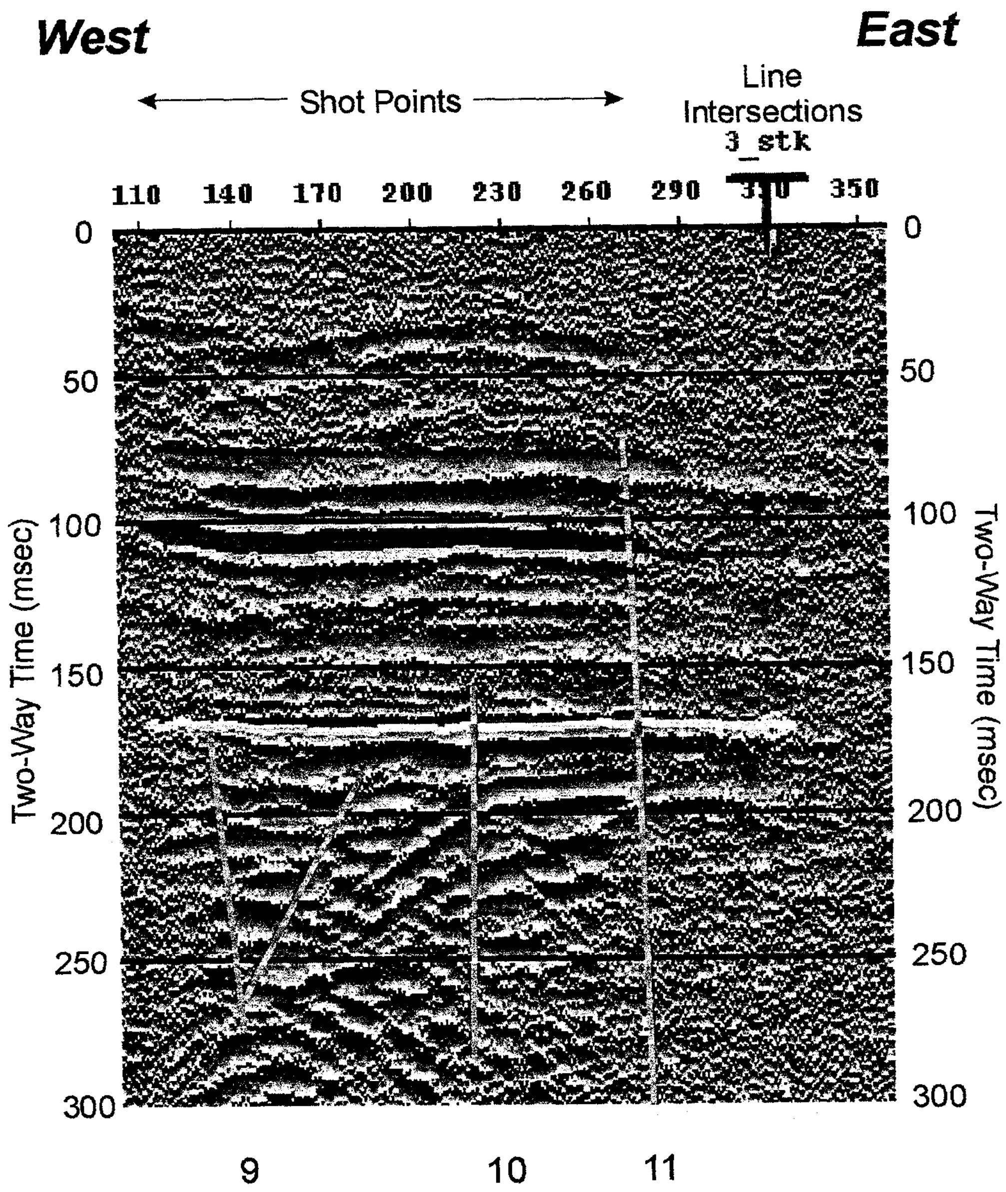
Oak Ridge, Tennessee

Figure No. 9B	**Line 1B**
Project No. 2901SAI	**Instantaneous Phase Section**
File No. *2901sai\Interp1B.cdr*	*Paducah Gaseous Diffusion Plant*
Date: Dec., 2001	*Paducah, Kentucky*



Explanation

Interpreted Top McNairy Formation

Interpreted Top Limestone

Interpreted Fault

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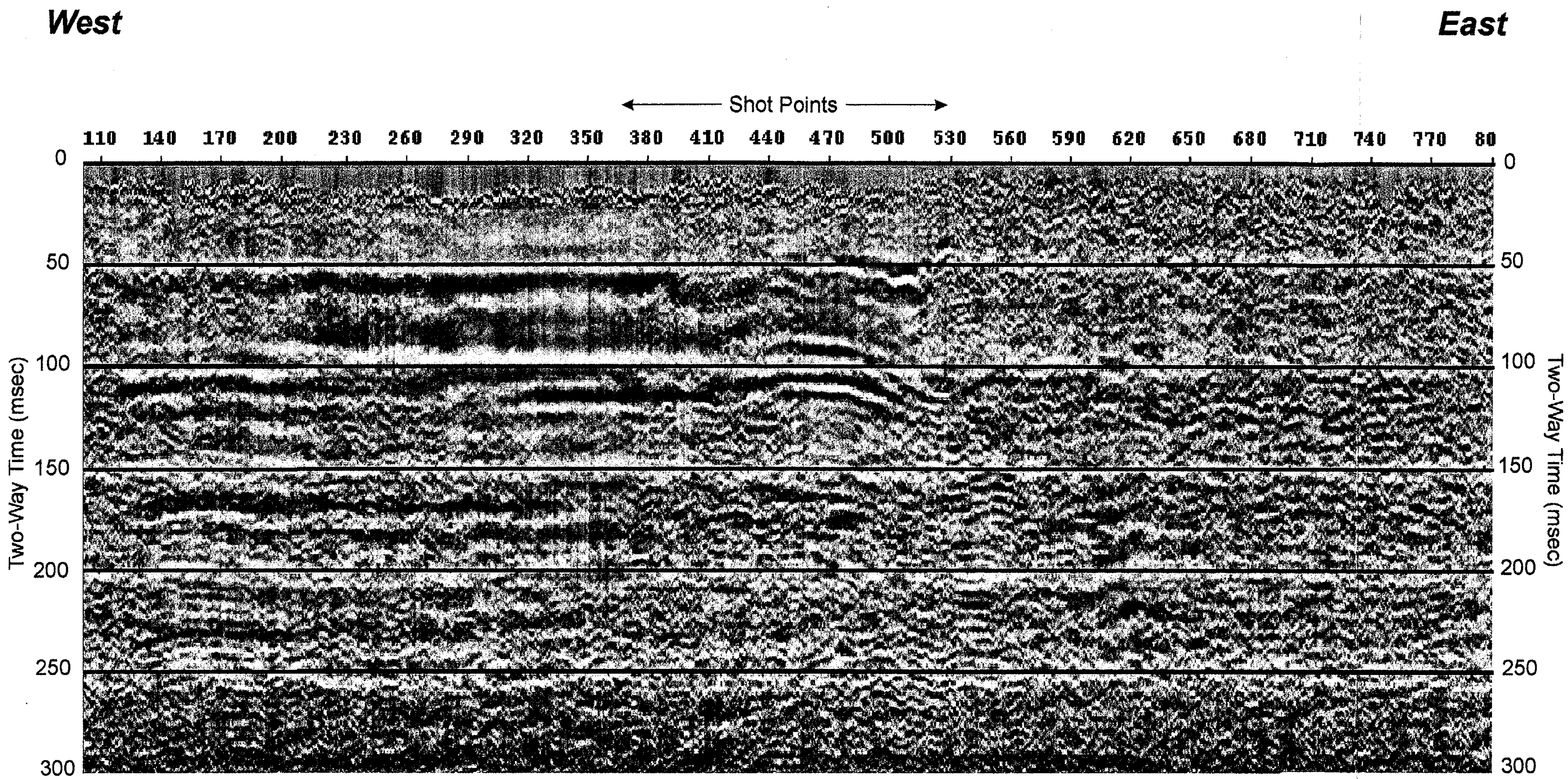
SAIC
Oak Ridge, Tennessee

Figure No. 9C	**Line 1B Interpreted Instantaneous Phase Section**
Project No. 2901SAI	
File No. *2901sai\Interp1B.cdr*	*Paducah Gaseous Diffusion Plant Paducah, Kentucky*
Date: Dec., 2001	



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Oak Ridge, Tennessee

Figure No. 10A

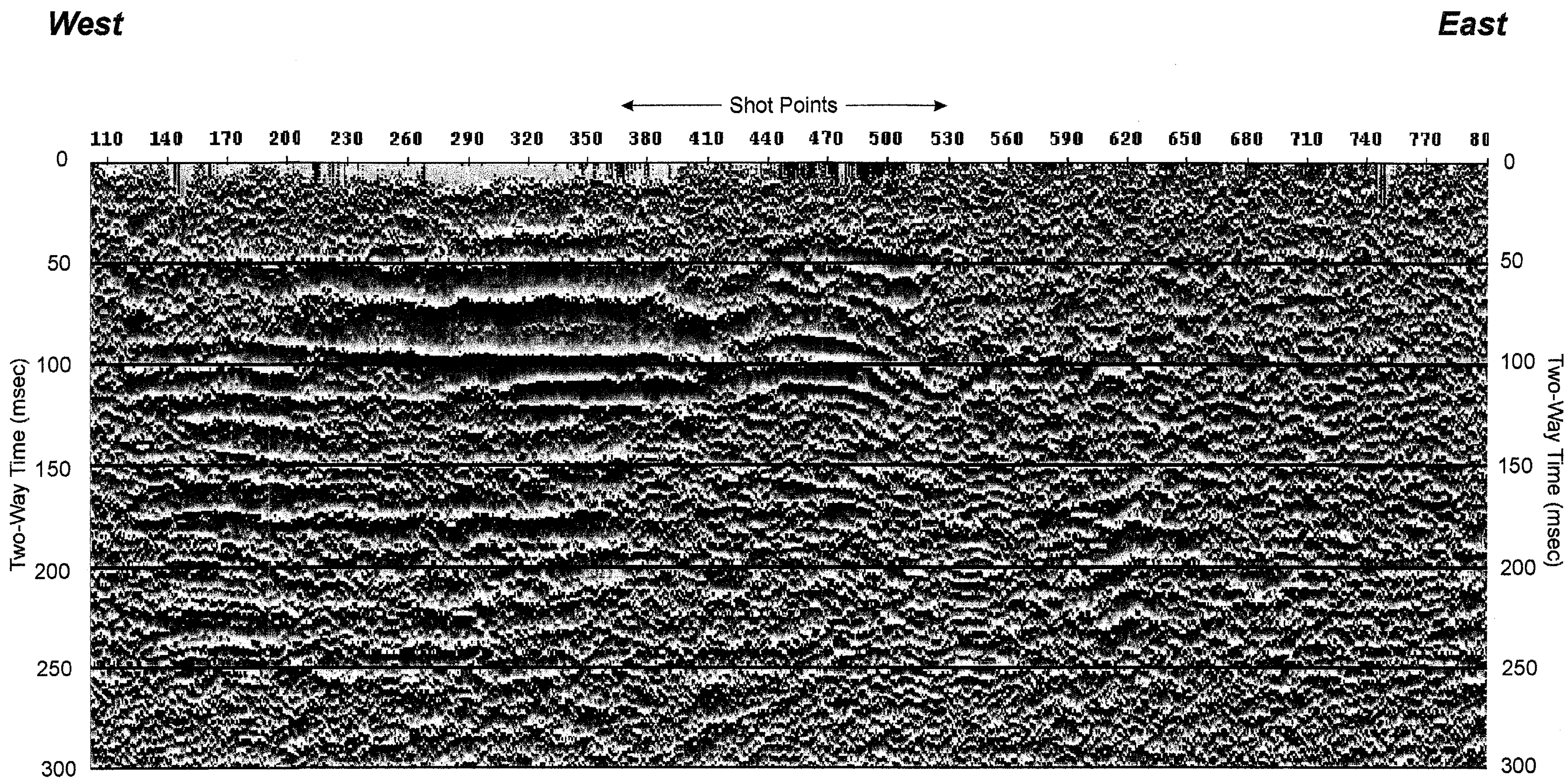
Project No. 2901SAI

File No. *2901sai\Grayscale-2.cdr*

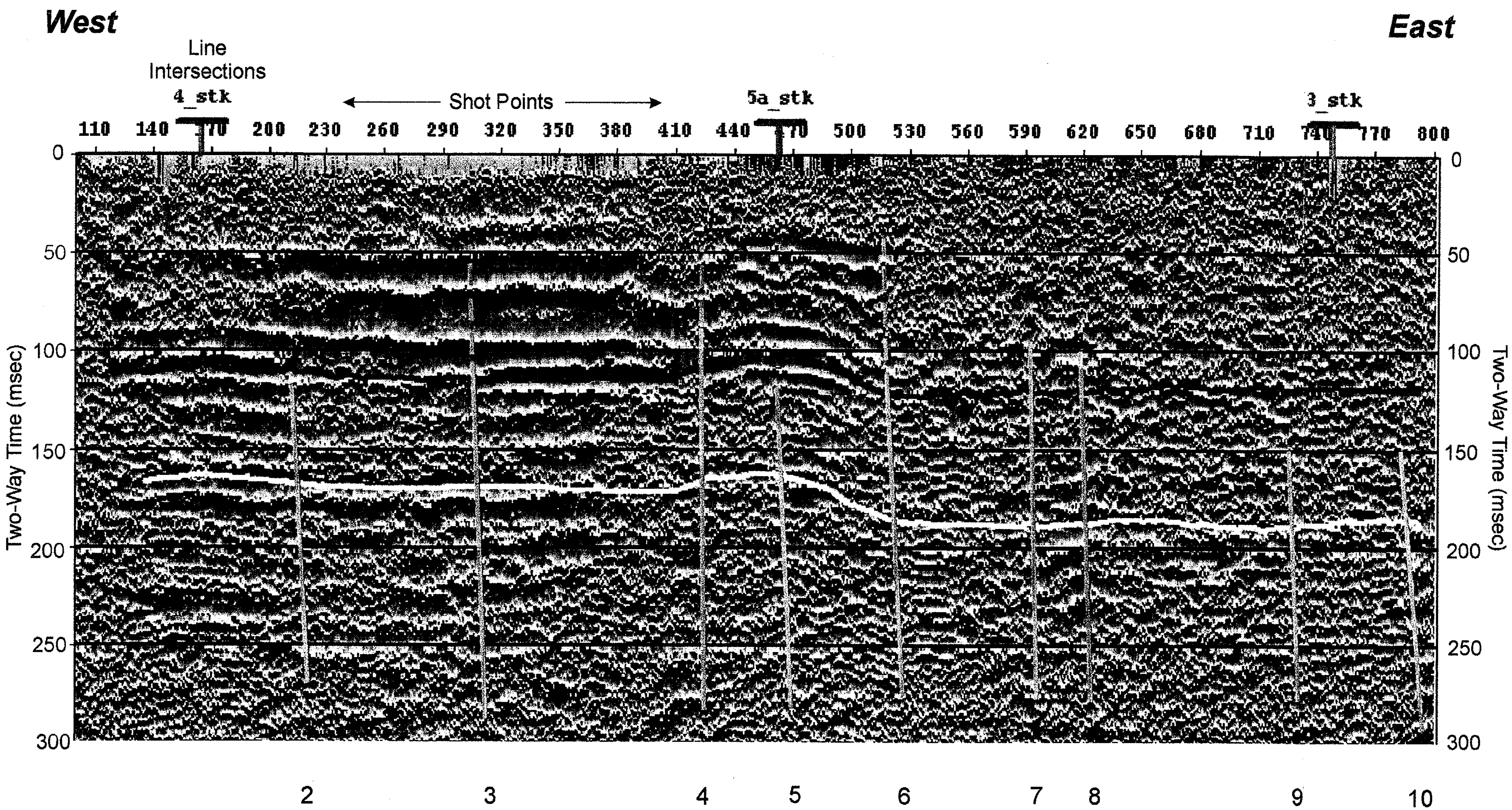
Date: Dec., 2001

Line 2
Enhanced Stack (grayscale)

Paducah Gaseous Diffusion Plant
Paducah, Kentucky



BLACKHAWK GeoServices Southeast Region	SAIC Oak Ridge, Tennessee
Figure No. 10B Project No. 2901SAI File No. 2901sai\Uninterp2.cdr Date: Dec., 2001	**Line 2** **Instantaneous Phase Section** *Paducah Gaseous Diffusion Plant* *Paducah, Kentucky*



Explanation

Interpreted Top McNairy Formation

Interpreted Top Limestone

Interpreted Fault

BLACKHAWK GeoServices *Southeast Region*

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Oak Ridge, Tennessee

Figure No.
10C

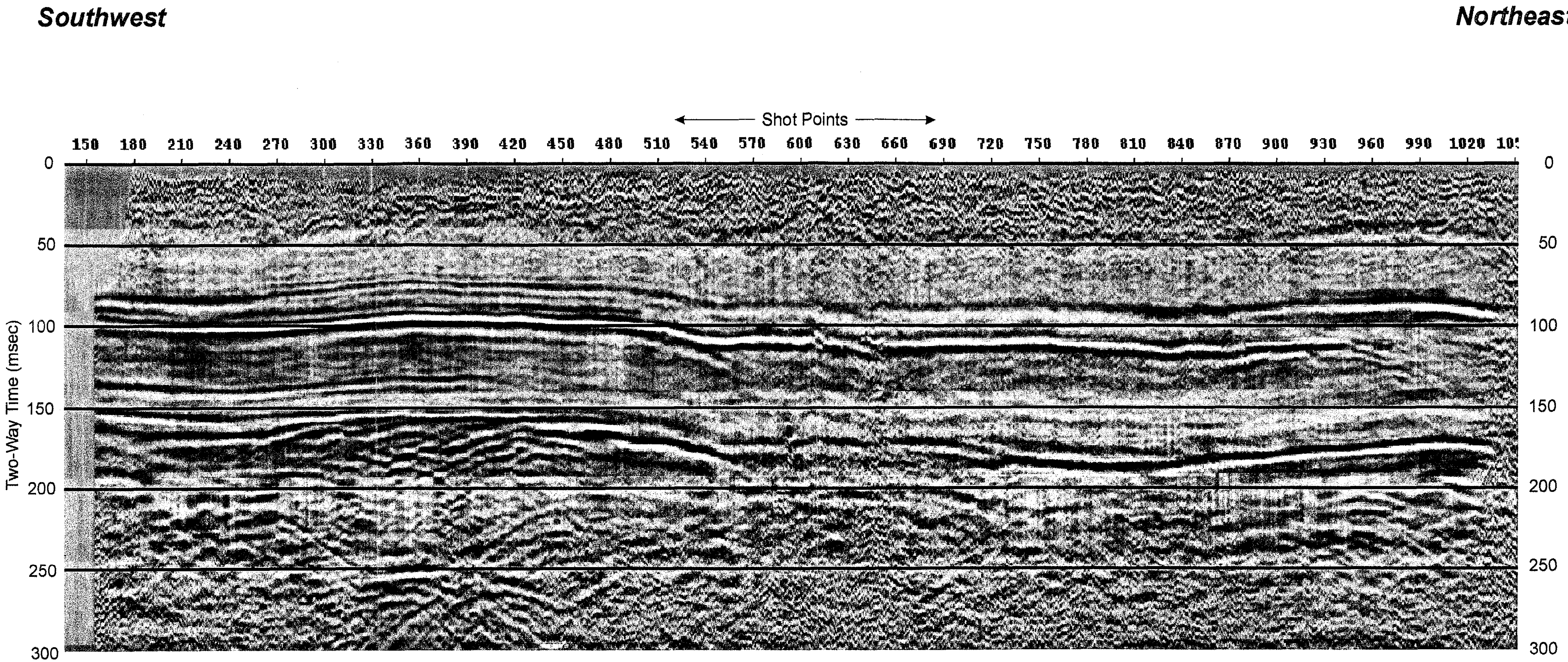
Project No.
2901SAI

File No.
2901sai\Interp2.cdr

Date:
Dec., 2001

Line 2
Interpreted Instantaneous Phase Section

Paducah Gaseous Diffusion Plant
Paducah, Kentucky



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Southeast Region

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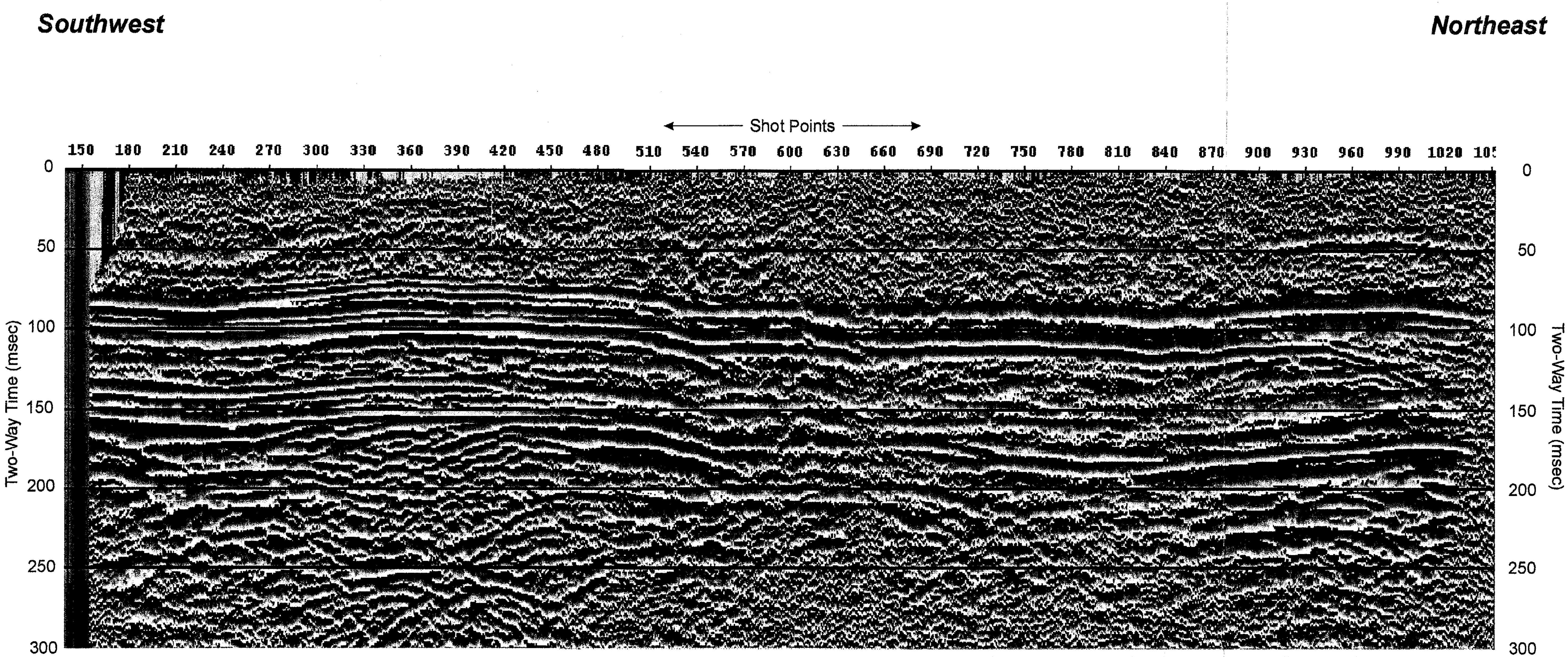
Oak Ridge, Tennessee

Figure No. 11A
Project No. 2901SAI
File No. 2901saiGrayscale-3.cdr
Date: Dec., 2001

Line 3
Enhanced Stack (grayscale)

Paducah Gaseous Diffusion Plant
Paducah, Kentucky



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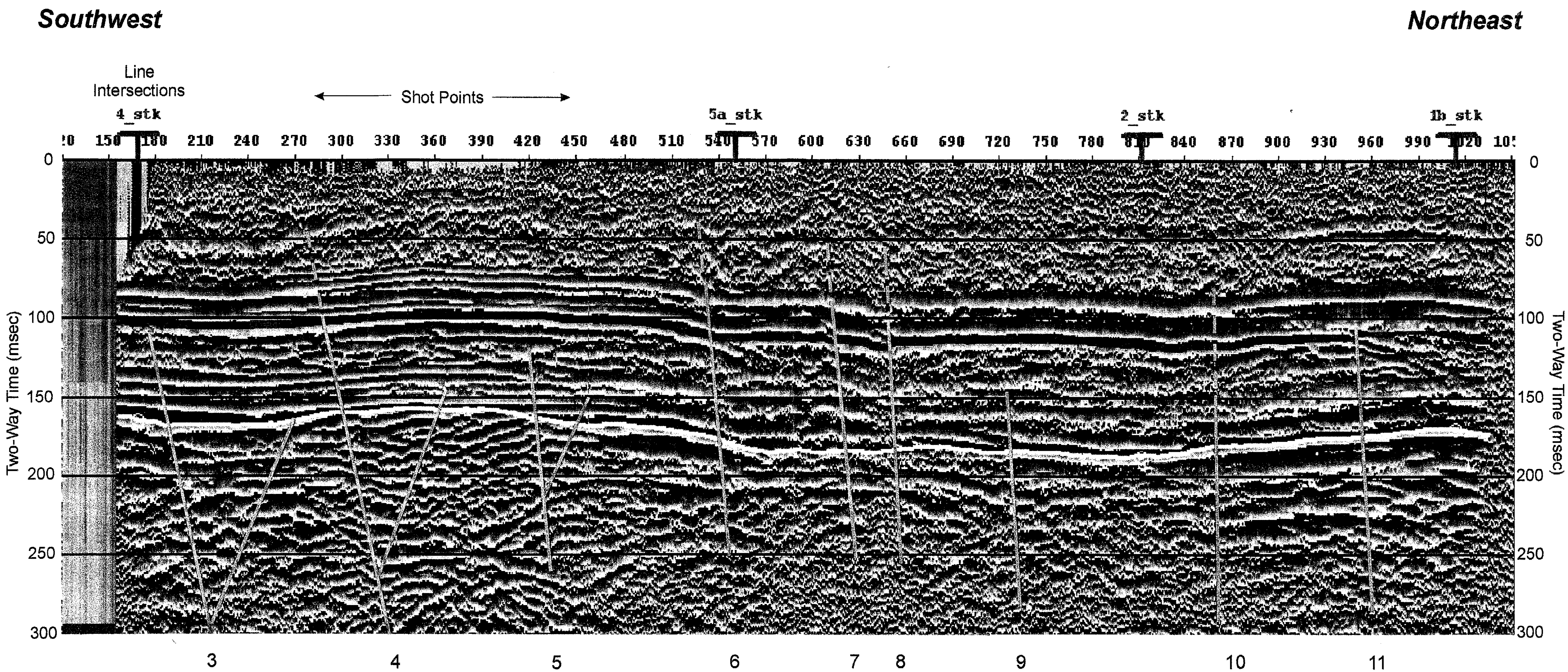
Oak Ridge, Tennessee

Figure No. 11B	**Line 3 Instantaneous Phase Section**
Project No. 2901SAI	*Paducah Gaseous Diffusion Plant Paducah, Kentucky*
File No. *2901sai\Uninterp3.cdr*	
Date: Dec., 2001	



Explanation

Interpreted Top McNairy Formation

Interpreted Top Limestone

Interpreted Fault

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Oak Ridge, Tennessee

Figure No. 11C

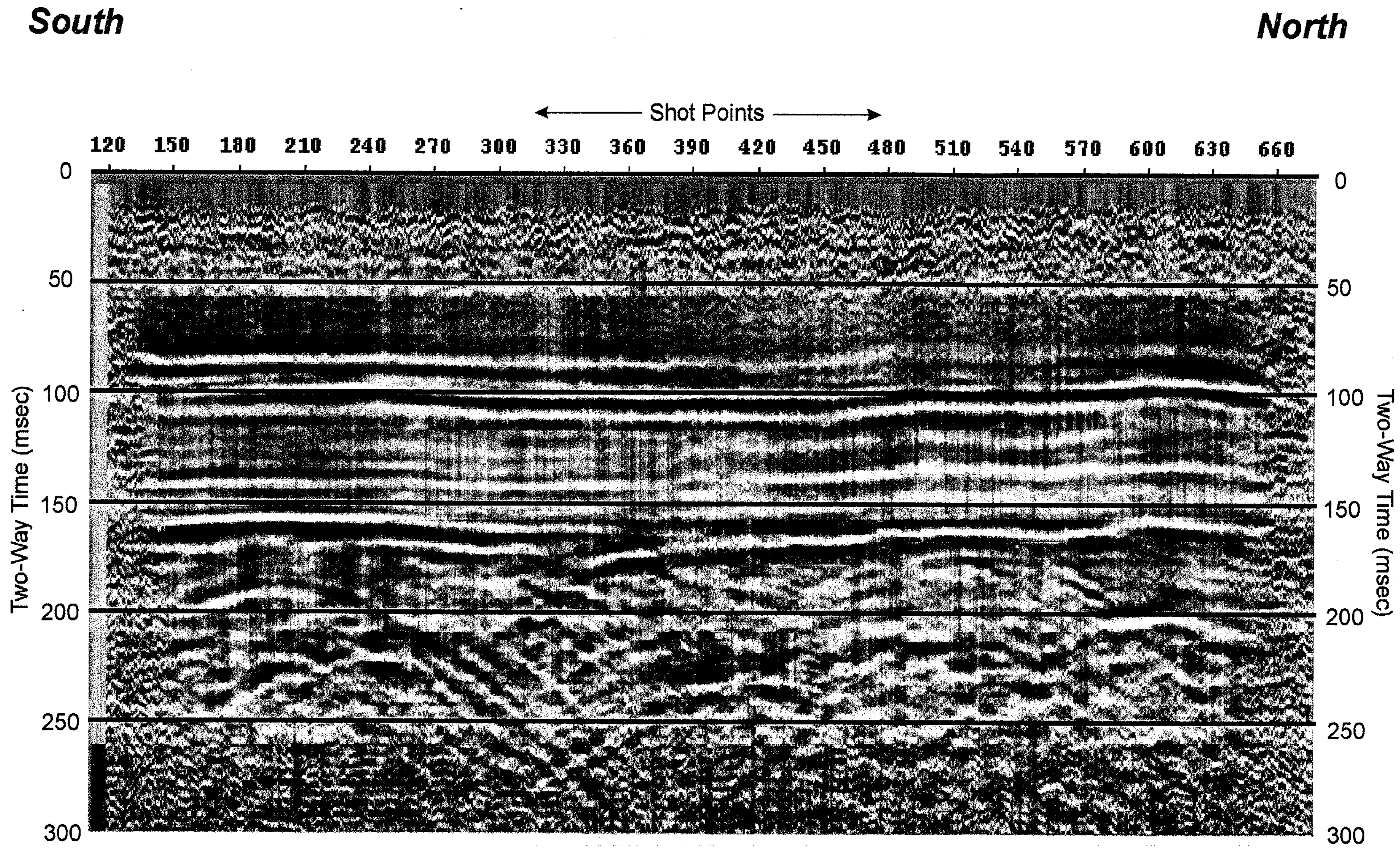
Project No. 2901SAI

File No. *2901sai\Interp3.cdr*

Date: Dec., 2001

Line 3
Interpreted Instantaneous Phase Section

Paducah Gaseous Diffusion Plant
Paducah, Kentucky



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Oak Ridge, Tennessee

Figure No. 12A	**Line 4** **Enhanced Stack (grayscale)**
Project No. 2901SAI	*Paducah Gaseous Diffusion Plant*
File No. *2901sai\Grayscale-4.cdr*	*Paducah, Kentucky*
Date: Dec., 2001	

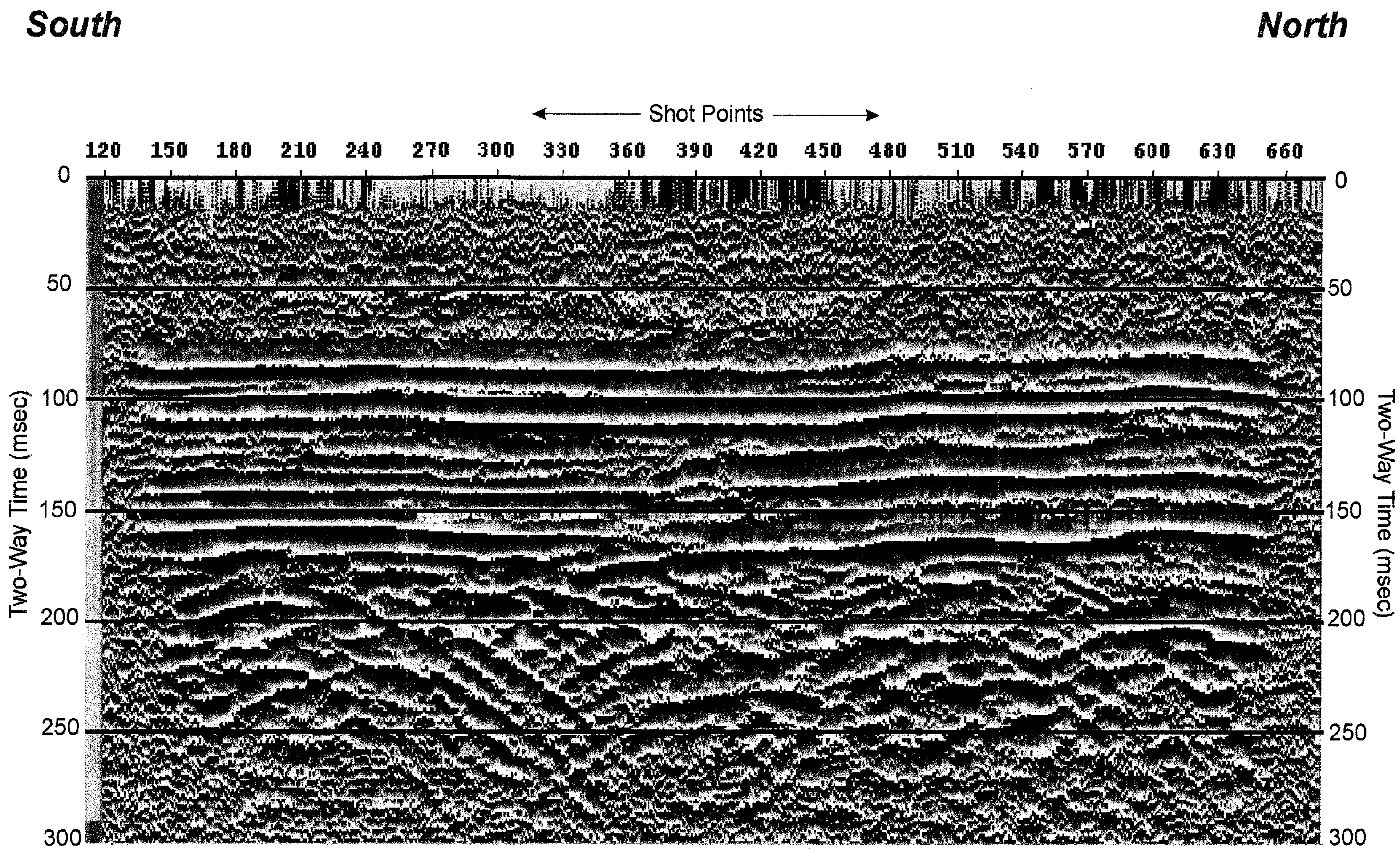

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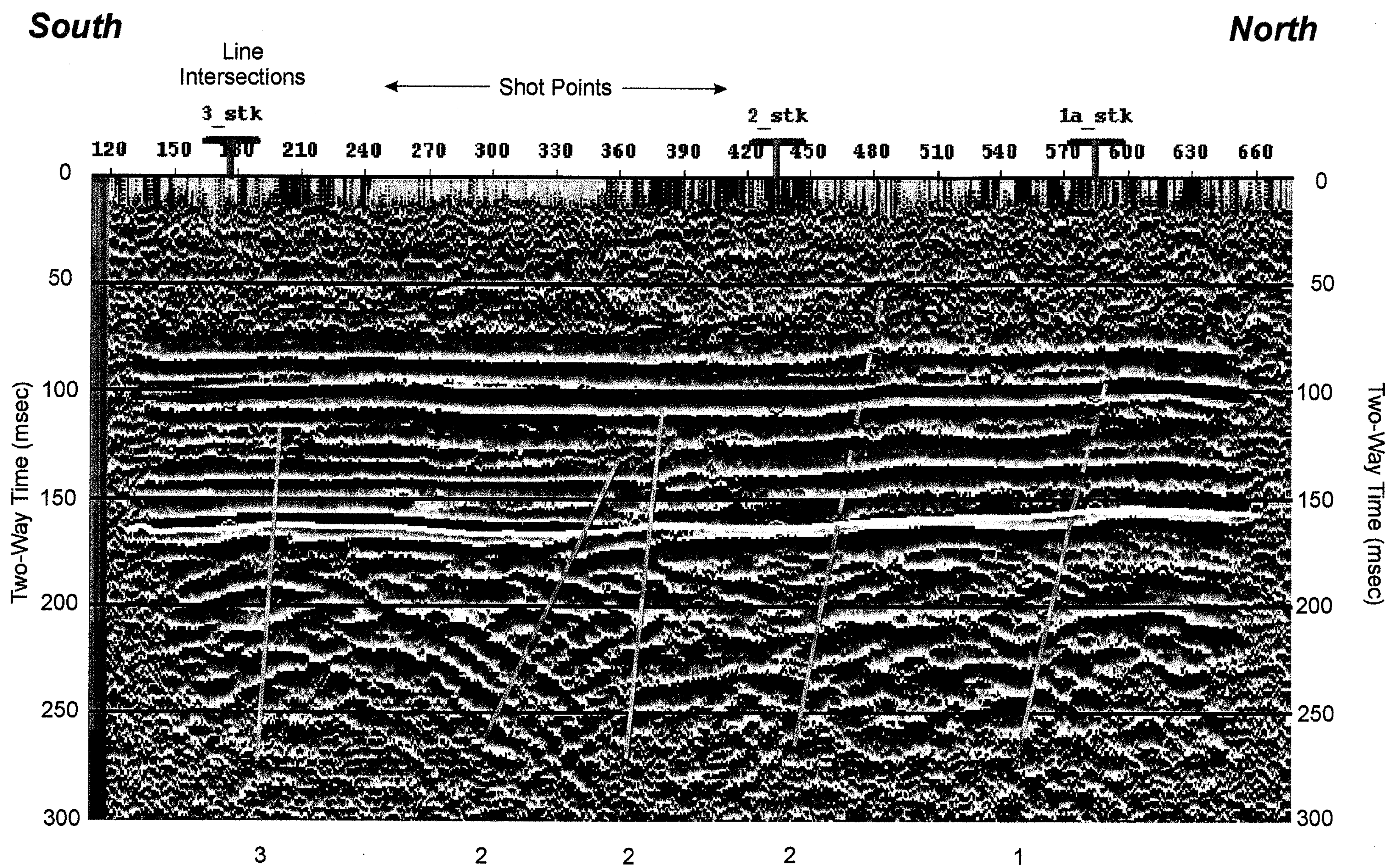
Figure No. 12B	**Line 4 Instantaneous Phase Section**
Project No. 2901SAI	*Paducah Gaseous Diffusion Plant*
File No. *2901sai\Uninterp4.cdr*	*Paducah, Kentucky*
Date: Dec., 2001	



Explanation

Interpreted Top McNairy Formation

Interpreted Top Limestone

Interpreted Fault

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SAIC
Oak Ridge, Tennessee

Figure No. 12C

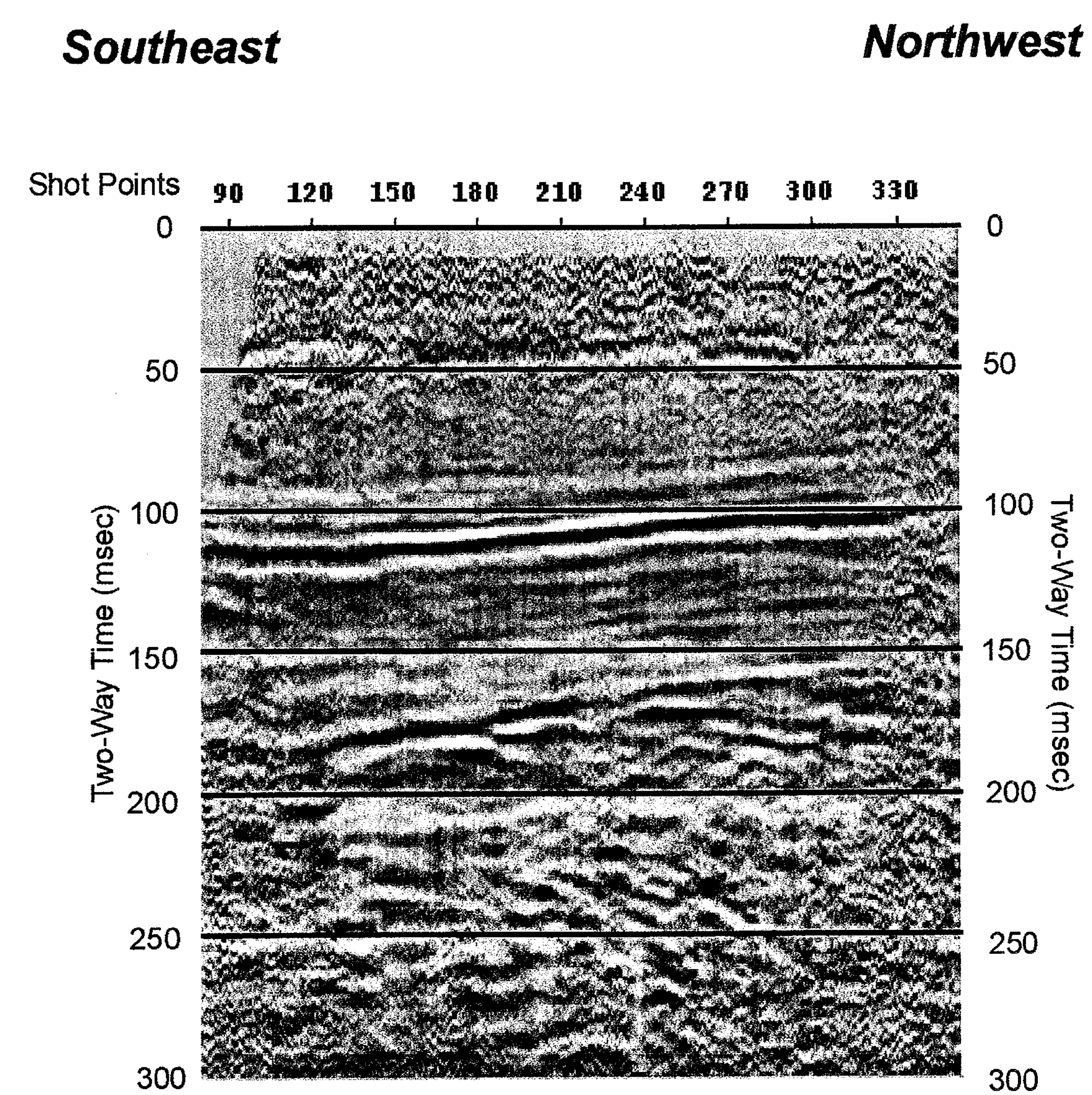
Project No. 2901SAI

File No. *2901sai\interp4.cdr*

Date: Dec., 2001

Line 4
Interpreted Instantaneous Phase Section

Paducah Gaseous Diffusion Plant
Paducah, Kentucky



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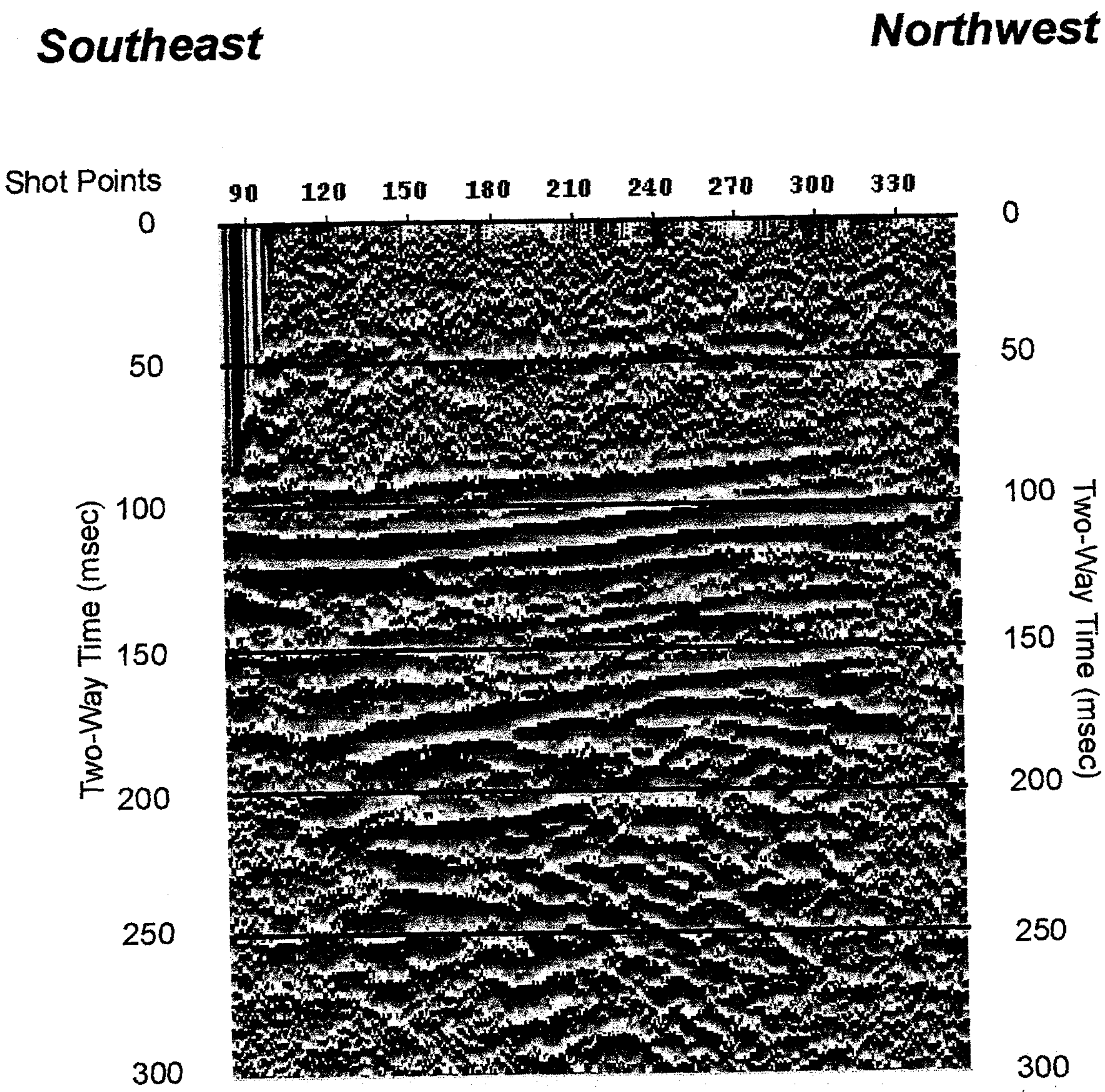
Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 13A	**Line 5A**
Project No. 2901SAI	**Enhanced Stack (grayscale)**
File No. 2901saiGrayscale-5A.cdr	*Paducah Gaseous Diffusion Plant Paducah, Kentucky*
Date: Dec., 2001	



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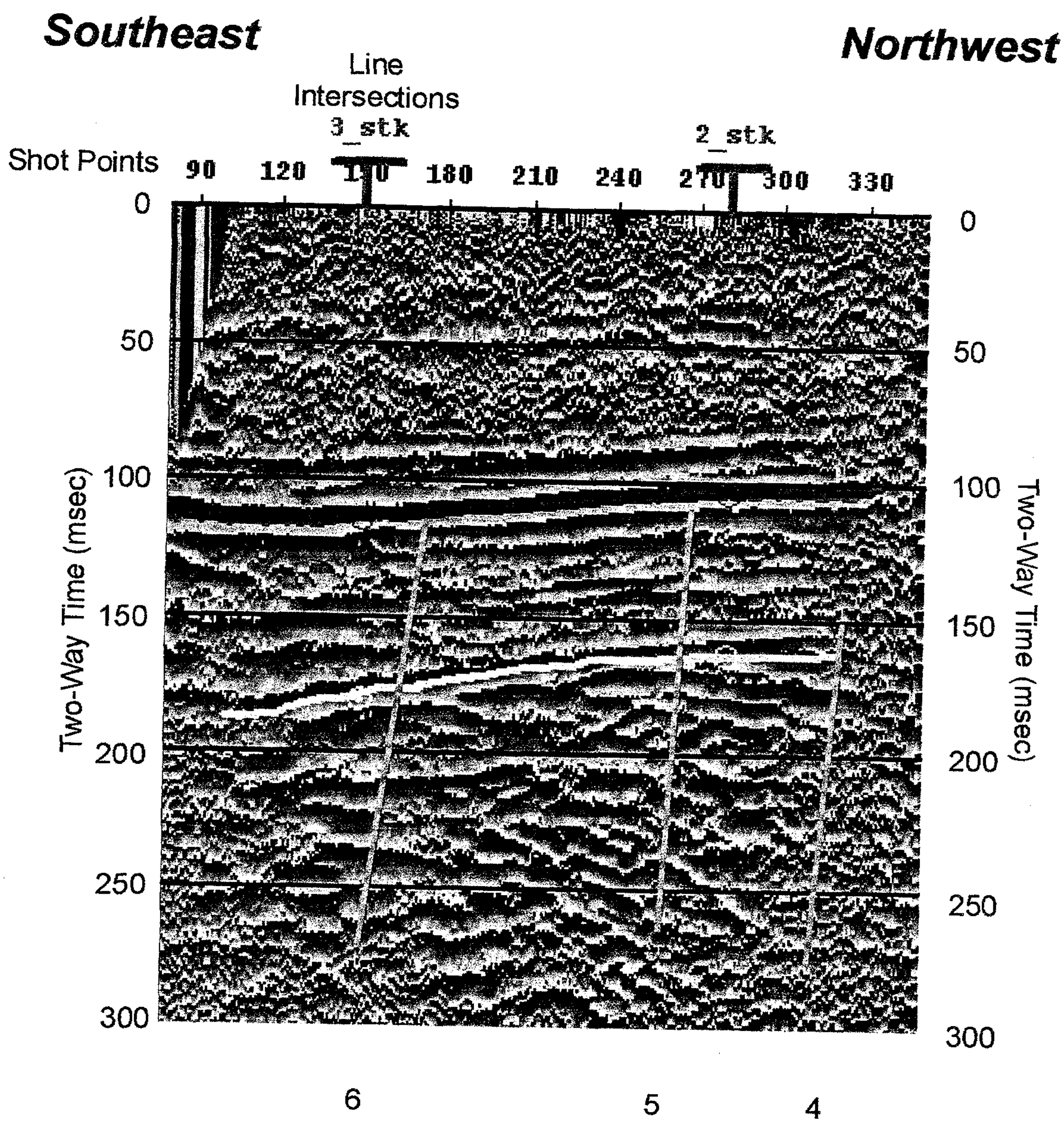
Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 13B	**Line 5A Instantaneous Phase Section**
Project No. 2901SAI	*Paducah Gaseous Diffusion Plant Paducah, Kentucky*
File No. *2901saiUninterp5A.cdr*	
Date: Dec., 2001	



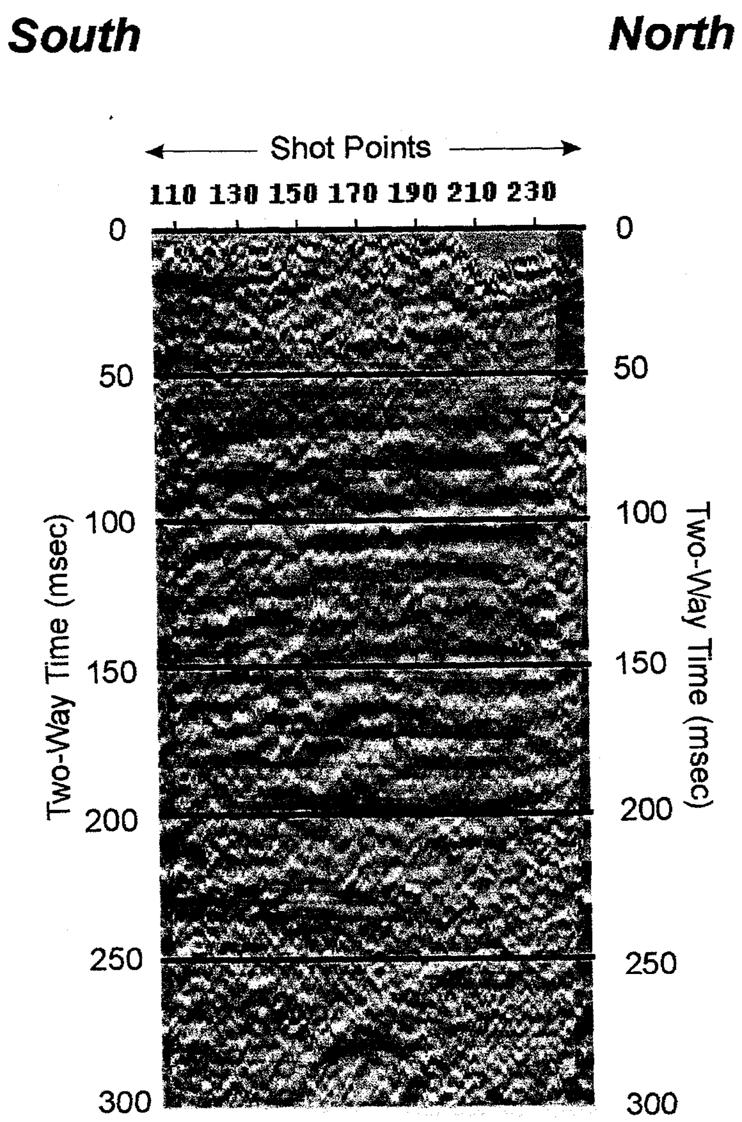
Explanation

Interpreted Top McNairy Formation

Interpreted Top Limestone

Interpreted Fault

BLACKHAWK *GeoServices* *Southeast Region*	SAIC *Oak Ridge, Tennessee*
Figure No. 13C	**Line 5A Interpreted Instantaneous Phase Section**
Project No. 2901SAI	
File No. *2901sai\Interp5A.cdr*	*Paducah Gaseous Diffusion Plant Paducah, Kentucky*
Date: Dec., 2001	



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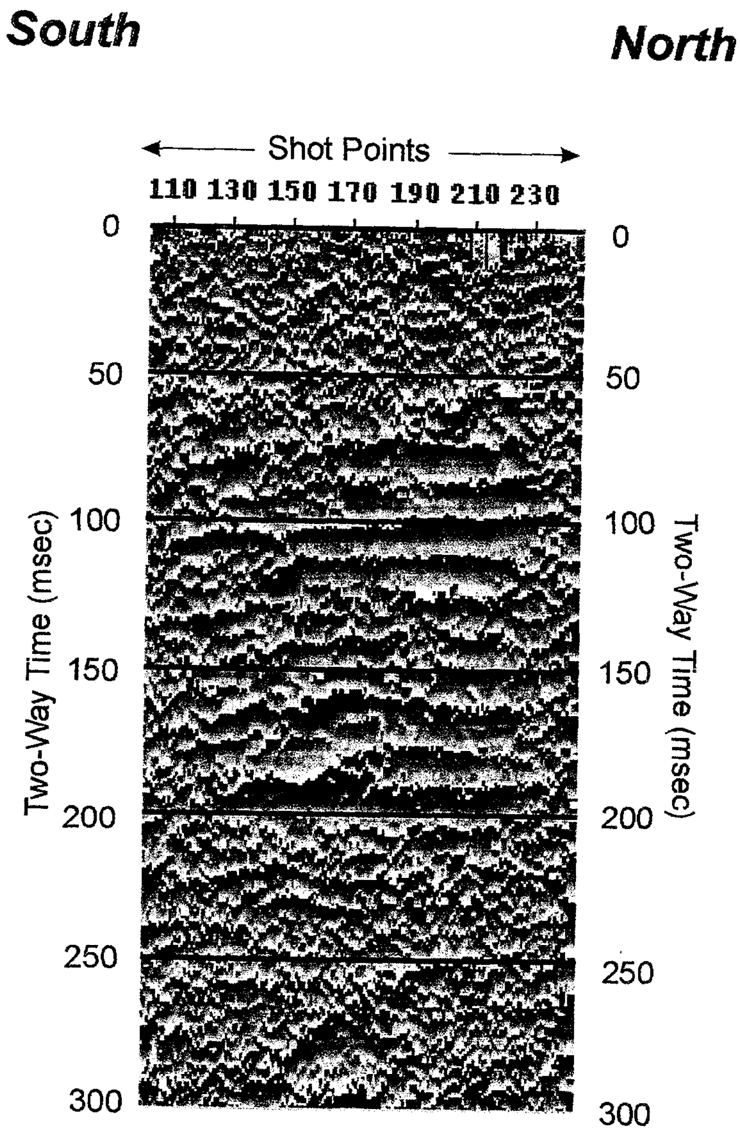
Southeast Region

SAIC
Oak Ridge, Tennessee

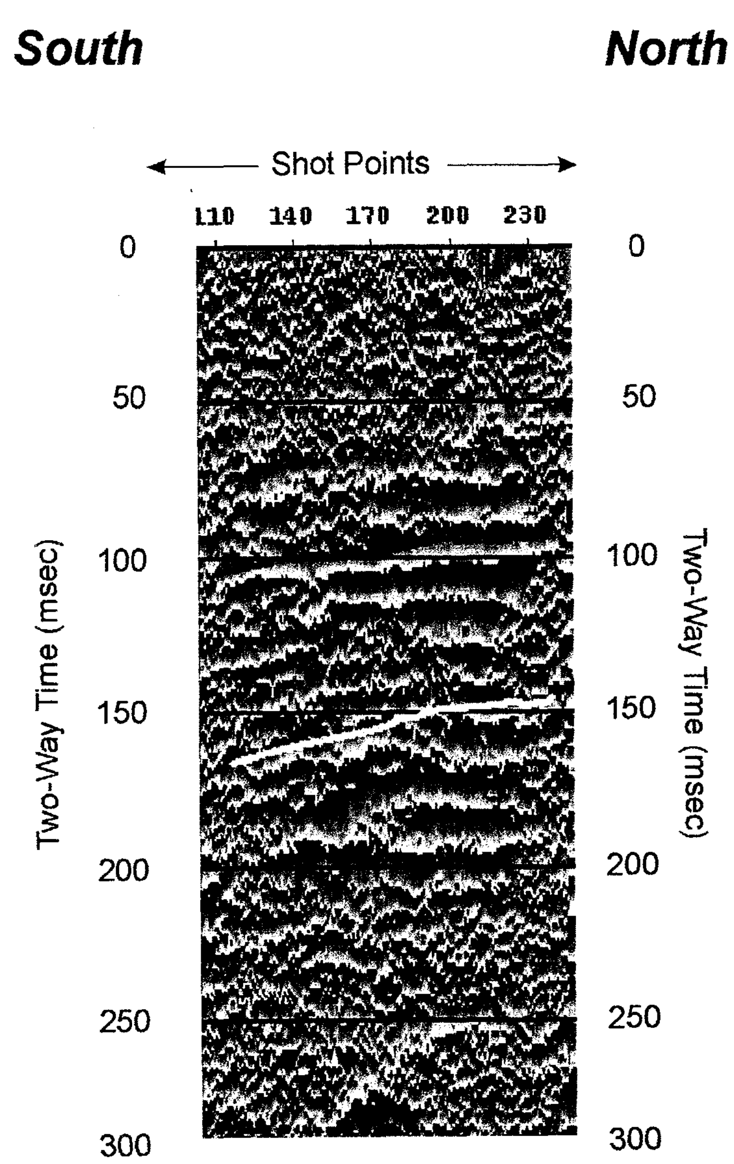
Figure No. 14A	**Line 5B** **Enhanced Stack (grayscale)**
Project No. 2901SAI	*Paducah Gaseous Diffusion Plant*
File No. *2901saiGrayscale-5B.cdr*	*Paducah, Kentucky*
Date: Dec., 2001	



BLACKHAWK GeoServices
Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 14B	**Line 5B Instantaneous Phase Section**
Project No. 2901SAI	*Paducah Gaseous Diffusion Plant*
File No. *2901sai\Uninterp5B.cdr*	*Paducah, Kentucky*
Date: Dec., 2001	



Explanation

Interpreted Top McNairy Formation

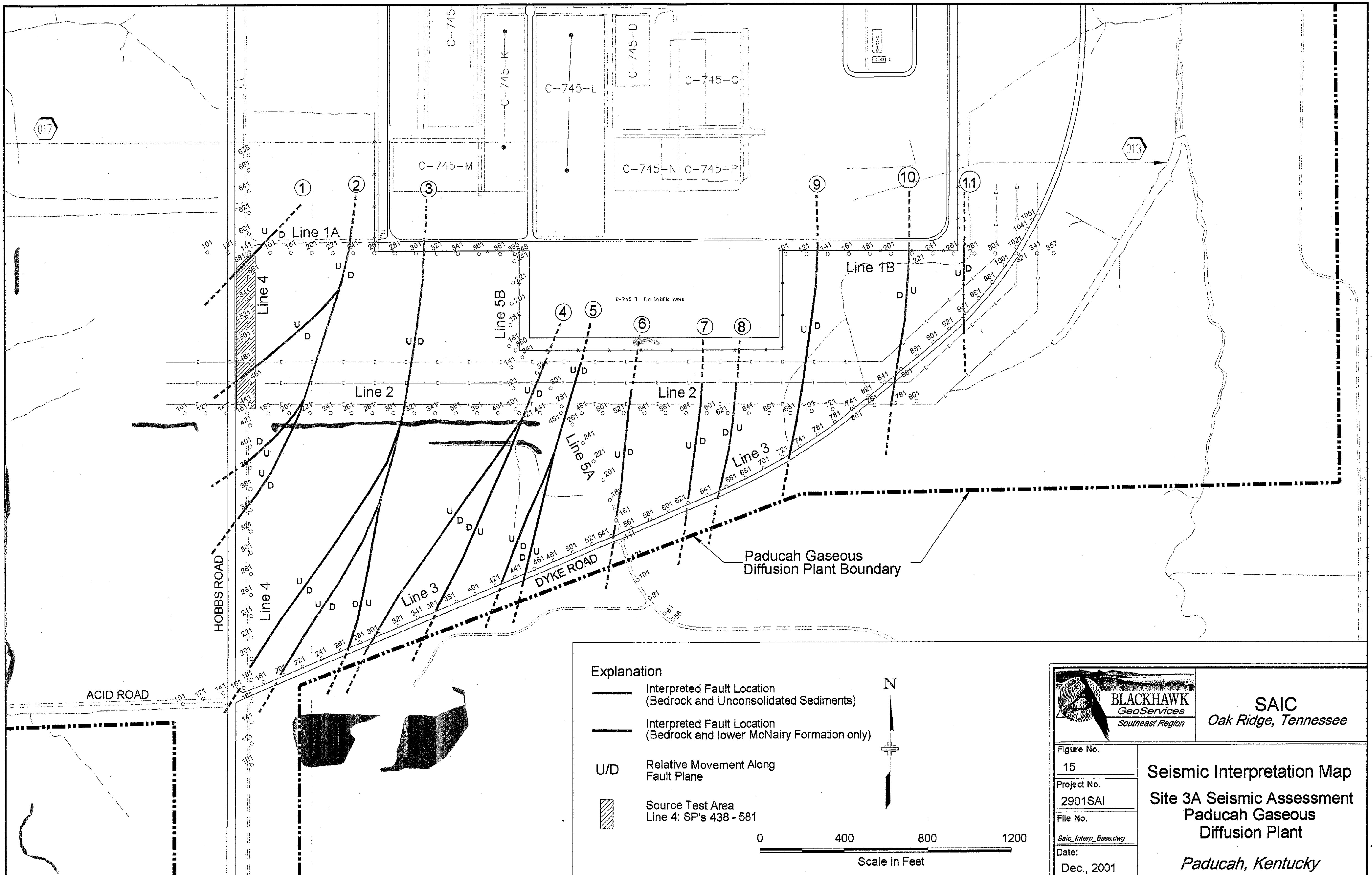
Interpreted Top Limestone

Interpreted Fault

BLACKHAWK GeoServices *Southeast Region*

SAIC
Oak Ridge, Tennessee

Figure No. 14C	**Line 5B Interpreted Instantaneous Phase Section**
Project No. 2901SAI	
File No. *2901sai\Interp5B.cdr*	*Paducah Gaseous Diffusion Plant Paducah, Kentucky*
Date: Dec., 2001	



SAIC
Oak Ridge, Tennessee

Figure No. 15

Project No. 2901SAI

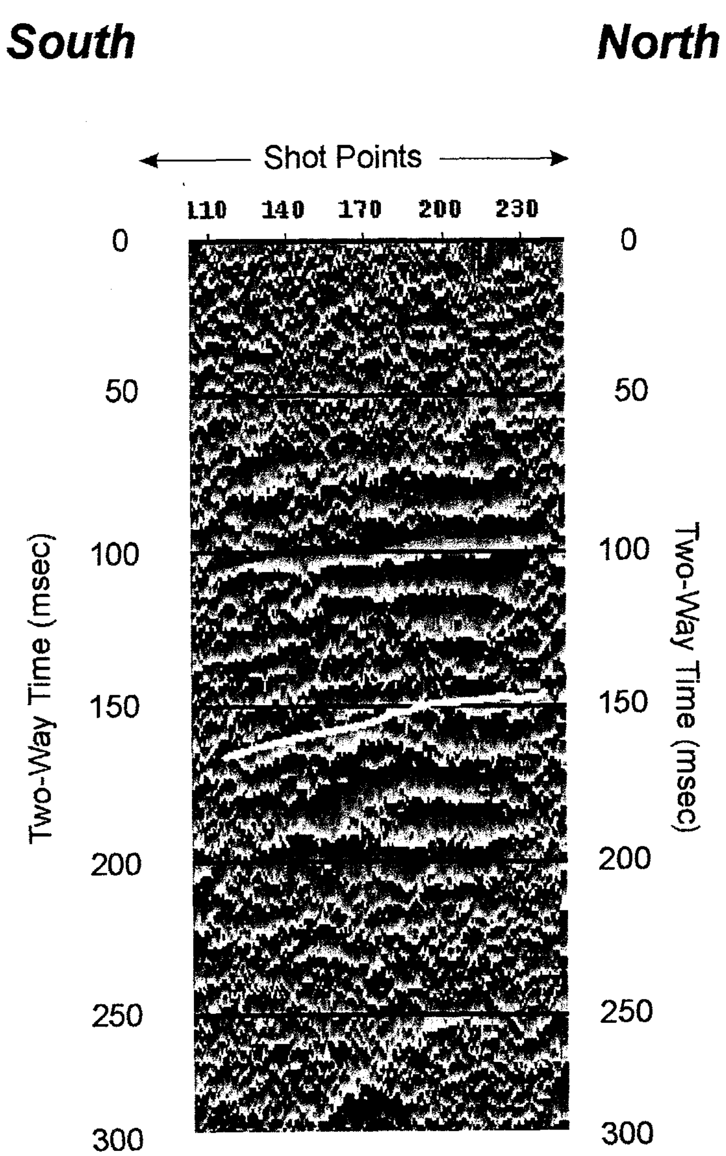
File No. Saic_Interp_Base.dwg

Date: Dec., 2001

Seismic Interpretation Map

Site 3A Seismic Assessment
Paducah Gaseous
Diffusion Plant

Paducah, Kentucky



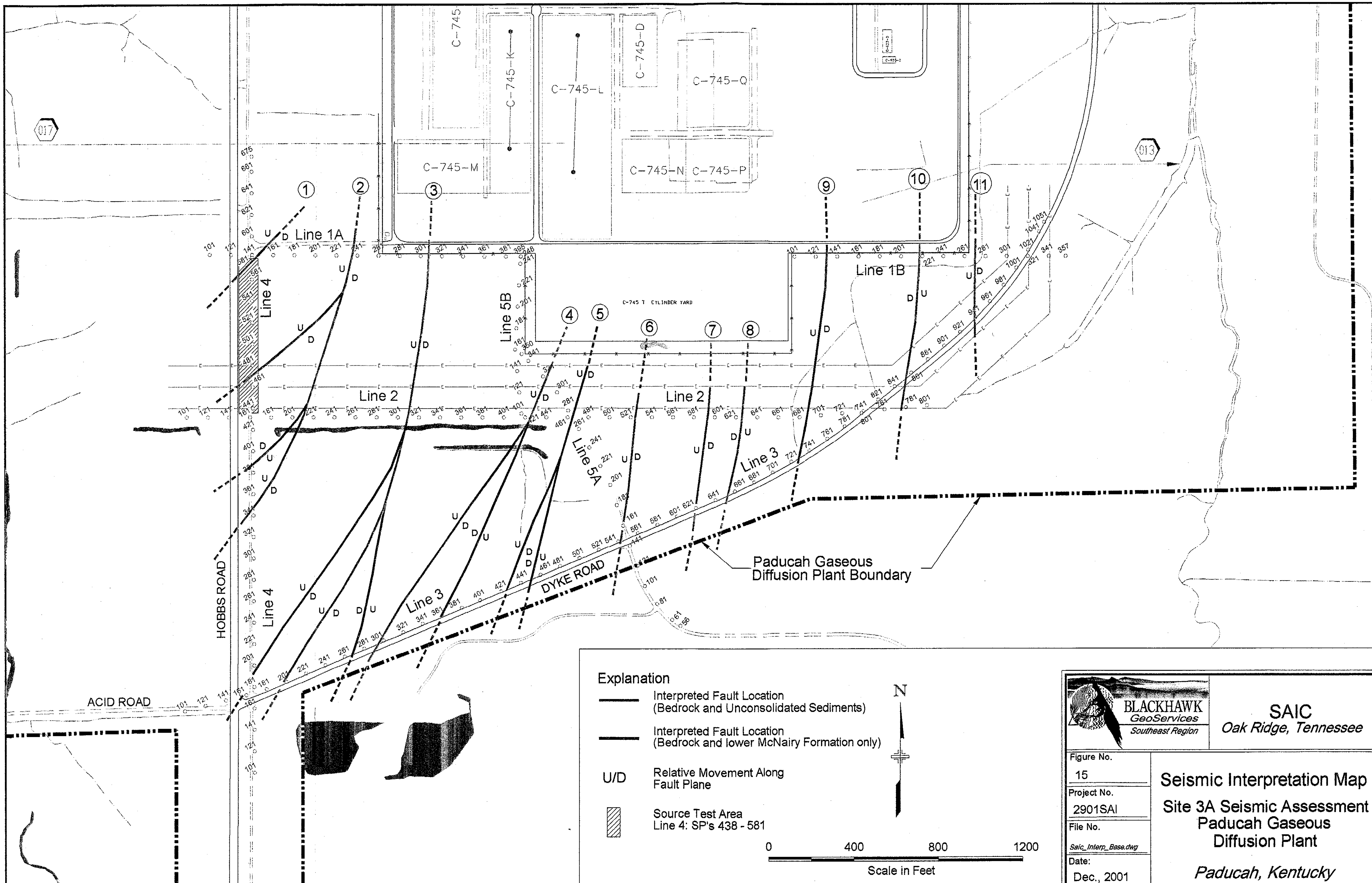
Explanation

Interpreted Top McNairy Formation

Interpreted Top Limestone

Interpreted Fault

BLACKHAWK GeoServices *Southeast Region*	SAIC *Oak Ridge, Tennessee*
Figure No. 14C	**Line 5B** **Interpreted Instantaneous Phase Section**
Project No. 2901SAI	
File No. *2901sai\Interp5B.cdr*	*Paducah Gaseous Diffusion Plant* *Paducah, Kentucky*
Date: Dec., 2001	



Explanation

Interpreted Fault Location (Bedrock and Unconsolidated Sediments)

Interpreted Fault Location (Bedrock and lower McNairy Formation only)

U/D Relative Movement Along Fault Plane

Source Test Area Line 4: SP's 438 - 581

N

0 400 800 1200

Scale in Feet

BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No.: 15

Project No.: 2901SAI

File No.: Saic_Interp_Base.dwg

Date: Dec., 2001

Seismic Interpretation Map

Site 3A Seismic Assessment
Paducah Gaseous Diffusion Plant

Paducah, Kentucky

ATTACHMENT C-II

P-WAVE SURVEY LINE ELEVATIONS AND COORDINATES

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P-Wave Survey Line Elevations and Coordinates

Line	Station	Elevation[a] (ft msl)	PGDP Coordinates[b] Northing (ft)	Easting (ft)
L1A	101	383.50	-5958.35	-4987.97
	121	383.62	-5959.11	-4887.96
	141	383.51	-5959.87	-4788.01
	161	380.57	-5960.63	-4687.99
	181	380.79	-5961.39	-4587.89
	201	380.87	-5962.15	-4488.04
	221	380.92	-5962.91	-4387.99
	241	381.19	-5963.67	-4288.00
	261	381.45	-5964.43	-4187.99
	281	381.27	-5965.19	-4088.00
	301	383.17	-5965.95	-3988.04
	321	383.43	-5966.71	-3887.99
	341	384.19	-5967.47	-3788.09
	361	384.06	-5968.23	-3688.05
	381	384.11	-5968.99	-3588.03
	395	384.86	-5969.53	-3518.08
L1B	101	386.49	-5971.52	-2221.74
	121	385.27	-5971.39	-2121.71
	141	384.82	-5971.25	-2021.72
	161	384.57	-5971.11	-1921.76
	181	384.24	-5970.98	-1821.81
	201	384.54	-5970.84	-1721.73
	221	384.18	-5970.70	-1621.72
	241	383.74	-5970.57	-1521.77
	261	383.96	-5970.43	-1421.81
	281	380.42	-5970.29	-1321.84
	301	383.54	-5970.17	-1221.83
	321	386.61	-5970.05	-1121.80
	341	382.46	-5969.94	-1021.81
	357	382.45	-5969.85	-941.73
L2	101	383.57	-6715.63	-5098.55
	121	384.30	-6715.77	-4998.57
	141	384.17	-6715.91	-4898.57
	161	385.02	-6716.06	-4798.55
	181	383.58	-6716.20	-4698.64
	201	383.23	-6716.34	-4598.50
	221	383.55	-6716.48	-4498.54
	241	383.44	-6716.63	-4398.55
	261	383.63	-6716.77	-4298.68
	281	383.54	-6716.91	-4198.57
	301	383.72	-6717.05	-4098.60
	321	384.05	-6717.25	-3998.56
	341	384.79	-6717.40	-3898.58
	361	386.06	-6717.54	-3798.57
	381	387.46	-6717.69	-3698.59
	401	388.12	-6717.84	-3598.43
	421	391.60	-6717.99	-3498.61
	441	392.05	-6718.13	-3398.59
	461	392.78	-6718.28	-3298.46
	481	393.09	-6718.43	-3198.54
	501	392.65	-6718.58	-3098.56
	521	392.72	-6718.65	-2998.51

P-Wave Survey Line Elevations and Coordinates (continued)

Line	Station	Elevation[a] (ft msl)	PGDP Coordinates[b] Northing (ft)	Easting (ft)
L2 (continued)	541	392.47	-6718.79	-2898.55
	561	392.05	-6718.93	-2798.48
	581	392.20	-6719.08	-2698.47
	601	392.54	-6719.22	-2598.49
	621	392.04	-6719.36	-2498.55
	641	390.53	-6719.50	-2398.51
	661	389.05	-6719.65	-2298.48
	681	390.14	-6719.81	-2198.48
	701	391.20	-6710.52	-2098.92
	721	389.57	-6701.24	-1999.41
	741	391.34	-6691.94	-1899.73
	761	388.31	-6682.66	-1800.30
	781	389.49	-6673.37	-1700.68
	801	388.61	-6664.08	-1601.09
L3	101	386.21	-8086.44	-5107.96
	121	386.63	-8061.48	-5011.04
	141	386.16	-8036.56	-4914.29
	161	386.99	-8011.61	-4817.46
	181	386.68	-7983.60	-4721.56
	201	388.21	-7950.41	-4627.31
	221	388.90	-7911.76	-4535.00
	241	390.34	-7873.16	-4442.84
	261	392.45	-7834.53	-4350.58
	281	395.60	-7795.94	-4258.44
	301	398.66	-7757.31	-4166.18
	321	401.35	-7718.69	-4073.98
	341	403.32	-7680.06	-3981.72
	361	405.08	-7641.40	-3889.41
	381	405.65	-7604.75	-3796.39
	401	405.95	-7570.32	-3711.01
	421	405.12	-7528.32	-3611.62
	441	404.22	-7489.95	-3519.29
	461	403.82	-7451.65	-3426.59
	481	403.05	-7413.17	-3334.46
	501	402.38	-7374.86	-3242.08
	521	400.99	-7336.53	-3149.75
	541	399.88	-7297.75	-3057.55
	561	399.02	-7258.69	-2965.31
	581	398.62	-7220.15	-2873.05
	601	398.08	-7182.04	-2780.70
	621	397.52	-7143.53	-2688.38
	641	396.92	-7105.21	-2595.99
	661	395.85	-7065.31	-2504.22
	681	395.23	-7022.44	-2413.80
	701	394.67	-6976.13	-2325.09
	721	393.87	-6926.93	-2238.10
	741	393.46	-6874.79	-2152.64
	761	393.12	-6819.78	-2069.08
	781	392.58	-6761.96	-1987.45
	801	391.58	-6700.71	-1908.32
	821	391.11	-6638.07	-1830.30

P-Wave Survey Line Elevations and Coordinates (continued)

Line	Station	Elevation[a] (ft msl)	PGDP Coordinates[b] Northing (ft)	Easting (ft)
L3	841	390.71	-6575.32	-1752.40
(continued)	861	390.30	-6512.71	-1674.30
	881	390.02	-6449.93	-1596.28
	901	389.61	-6387.36	-1518.33
	921	388.76	-6322.41	-1442.33
	941	387.66	-6253.19	-1370.11
	961	386.85	-6180.58	-1301.21
	981	386.42	-6104.56	-1236.28
	1001	386.12	-6024.21	-1176.45
	1021	385.50	-5941.93	-1119.58
	1041	384.83	-5856.36	-1067.68
	1051	384.52	-5812.39	-1043.94
L4	101	387.12	-8373.55	-4777.59
	121	386.83	-8273.47	-4778.05
	141	386.91	-8173.54	-4778.50
	161	387.36	-8073.65	-4778.95
	181	387.29	-7973.49	-4779.41
	201	386.71	-7873.42	-4779.85
	221	386.20	-7773.51	-4780.31
	241	386.00	-7673.55	-4780.75
	261	385.81	-7573.47	-4781.20
	281	385.79	-7473.43	-4781.65
	301	385.54	-7373.59	-4782.13
	321	385.28	-7273.55	-4782.50
	341	385.20	-7173.59	-4782.96
	361	385.06	-7073.51	-4783.42
	381	385.03	-6973.55	-4783.88
	401	385.25	-6873.52	-4784.34
	421	385.05	-6773.58	-4784.80
	441	384.61	-6673.47	-4785.26
	461	384.28	-6573.56	-4785.72
	481	383.91	-6473.55	-4786.17
	501	383.75	-6373.49	-4786.61
	521	383.49	-6273.53	-4787.07
	541	383.30	-6173.52	-4787.47
	561	382.83	-6073.48	-4787.93
	581	383.21	-5973.53	-4788.40
	601	383.50	-5873.59	-4788.86
	621	382.56	-5773.45	-4789.33
	641	382.05	-5673.52	-4789.80
	661	381.55	-5573.43	-4790.27
	675	381.25	-5503.41	-4790.59
L5A	101	398.97	-7506.04	-2932.97
	121	398.32	-7412.39	-2967.97
	141	399.50	-7318.54	-3002.89
	161	398.42	-7223.89	-3034.87
	181	397.28	-7128.27	-3064.71
	201	396.93	-7033.26	-3095.95
	221	396.23	-6944.92	-3142.76
	241	395.68	-6859.39	-3194.61
	261	395.20	-6772.79	-3244.49
	281	394.42	-6686.69	-3295.57

P-Wave Survey Line Elevations and Coordinates (continued)

Line	Station	Elevation[a] (ft msl)	PGDP Coordinates[b] Northing (ft)	Easting (ft)
L5A (continued)	301	393.11	-6601.45	-3347.95
	321	391.98	-6526.71	-3414.09
	341	389.17	-6454.38	-3482.98
	350	387.86	-6422.71	-3514.75
L5B	101	395.07	-6700.57	-3516.45
	121	388.34	-6601.12	-3526.18
	141	388.16	-6501.64	-3535.92
	161	388.92	-6402.13	-3545.66
	167	389.95	-6372.31	-3548.63

[a]Basis for elevations is the U.S. Coastal and Geodetic Survey North American Vertical Datum of 1988.

[b]Basis for coordinates is the U.S. Coastal and Geodetic Survey North American Datum of 1983. Coordinates are presented using the PGDP coordinate system.

ATTACHMENT C-III

GPR CALIBRATION SURVEY RESULTS

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BLACKHAWK
GeoServices
Southeast Region

GROUND PENETRATING RADAR SURVEY REPORT

Site 3A Seismic Assessment Paducah Gaseous Diffusion Plant

Paducah, Kentucky

Blackhawk GeoServices Project No. 2901SAI

Prepared for

Science Applications International Corporation
151 Lafayette Drive
Oak Ridge, Tennessee 37830

Prepared by

Blackhawk GeoServices
706 S. Illinois Ave., Suite D-104
Oak Ridge, Tennessee 37830
(865) 483-0200

January 18, 2002

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) is the lead agency at the Paducah Gaseous Diffusion Plant (PGDP). The U.S. Environmental Protection Agency (EPA) and the Commonwealth of Kentucky pursuant to the Federal Facility Agreement (FFA) regulate environmental restoration activities at PGDP.

Over the past year, representatives from EPA, the Commonwealth of Kentucky, and DOE and their support staffs have developed a field investigation program to address seismic issues associated with potentially siting a CERCLA waste disposal facility at the PGDP (BJC 2001). The results of these investigations will be used as input to the feasibility study of disposal options for CERCLA-derived waste at PGDP. One of the potential disposal facility sites presently under consideration is referred to as Site 3A. This site is located on DOE property, south of the present security fence.

As part of this field investigation program, Blackhawk GeoServices (BHG) performed a ground penetrating radar (GPR) calibration study on December 5 and 6, 2001. The GPR calibration study (GCS) was conducted near Barnes Creek in Massac County, Illinois and at Site 3A, just south of the PGDP property boundary fence.

The purpose of the GCS is two-fold. The first GCS objective is to determine the value of the GPR method in screening the near surface for anomalies potentially caused by faults in an area of known near-surface faulting (i.e., Barnes Creek). Using the Barnes Creek survey results as a benchmark, the second objective is to employ the GPR method as part of the near-surface investigation of potential faulting at Site 3A. The target zone for the GCS is generally considered to be the upper 5 to 10 feet of subsurface where near surface loess and/or fine-grained continental deposits are present.

The Barnes Creek portion of the GCS was conducted as a "blind test" approximately 150 feet north of Barnes Creek in an area where the near surface expression of faults is evident along the banks of the creek. Data from four low-frequency antennas were acquired along one survey line approximately 1,500 in length. At Site 3A, two low-frequency antennas were tested along a portion of the seismic p-wave survey line, identified as Line 5A.

This report summarizes the data acquisition and field methods used to conduct the GCS, and includes sections on data processing and results.

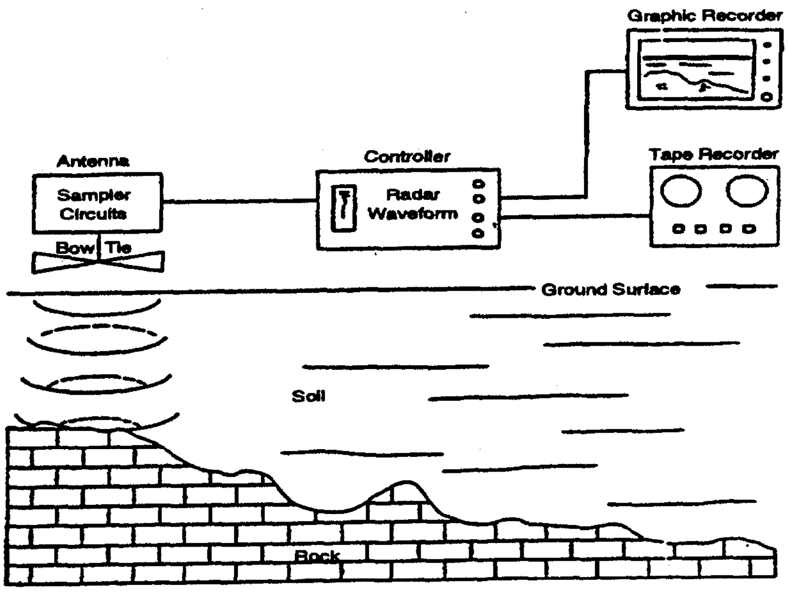
2.0 DATA ACQUISITION

This section describes the seismic methods and field procedures used to conduct the GCS including survey control, quality assurance (QA) signal testing, and production parameters.

2.1 GPR METHOD

GPR equipment used during this investigation consisted of a Geophysical Survey Systems, Inc. (GSSI) Model SIR-2P equipped with 200- and 100-megahertz (MHz) monostatic antennas, 80-, 40-, and 16-MHz bistatic antennas, and a DPU-5400 high-resolution thermal gray-scale printer.

When conducting a GPR survey, an antenna containing both a transmitter and a receiver is pulled along the ground surface. The transmitter radiates short pulses of high-frequency EM energy into the ground. The EM wave propagates into the subsurface at a velocity determined by the relative dielectric constant of the medium through which the wave travels. When the wave encounters the interface of two materials having different propagation velocities or some other electrical heterogeneity, such as soil and a fracture, a portion of the energy is reflected back to the surface (see diagram below). The contrast in velocity between the two media can be quantified by a reflection coefficient at the media interface. The magnitude of the reflection coefficient increases as the contrast in velocities increases; the coefficient sign is positive when the velocity increases at the interface and negative when it decreases. The reflected signal is detected at a receiver antenna, often as a characteristic triplet that is the result of the receiving antenna response and of multiples generated along the propagation path. The signal is transmitted to a control unit, displayed on a color monitor, and saved in the internal memory of the unit.



Schematic diagram of GPR operating system and EM signal reflection.

As predicted by Maxwell's equations for a propagating EM wave, two kinds of charge flow are generated by the associated alternating electric and magnetic fields (Ulriksen 1982). The charge flows are conduction and displacement currents. The conduction current term is predominant at lower frequencies, and conduction currents are used in the EM induction method. At the higher frequencies used in the GPR method, the displacement current term becomes predominant because the high frequencies will set bound charges in motion, causing polarization.

The physical properties that describe the movement of charges by conduction and displacement currents are the conductivity and the dielectric constant of the medium, respectively. Conductivity is a measure of the ease with which charges and charged particles move freely through the medium when subjected to an external electric field. The dielectric constant, or its value normalized by the dielectric constant of free space called the relative dielectric constant, is a measure of how easily a medium polarizes to accommodate the EM fields of a propagating wave (Keller and Frischknecht 1966).

Although conductivity has a smaller effect on the transmission of EM waves emitted from a GPR unit, it has an important effect on the attenuation of the waves (Ulriksen 1982). Highly conductive media will attenuate the EM signal rapidly and restrict depth penetration to the first several feet. Highly resistive (poorly conductive) media allow deeper penetration. The frequency of the transmitted waves also affects the depth of penetration. Lower frequencies penetrate deeper but have lower resolution, whereas higher frequencies can resolve smaller objects and soil layers at the expense of depth penetration. At many sites in the Southeastern U.S., soils are relatively conductive and depth penetration is often limited to 5 feet or less.

In unconsolidated materials, conduction occurs predominantly through pore fluids (Keller and Frischknecht 1966). Therefore, changes in pore fluid content, porosity, permeability, and degree of saturation will affect reflected and refracted EM signals. Faults and fractures in unconsolidated sediments, in which there may be different compaction densities relative to the surrounding area, can be identified in this manner. Also, the edges of anomalous zones sometimes exhibit diffraction patterns as a result of the transmitting and the receiving antennae being unfocused but emitting and receiving from a 45-degree cone. The cone allows the radar to detect subsurface variations or anomalies that are ahead of it, placing them deeper in time. As the radar approaches the anomaly, the reflection becomes shallower, with the shallowest reflection occurring when the radar is immediately above the feature. An identical pattern occurs as the antenna moves away from the feature.

Applications of GPR include mapping near-surface geology and landfill boundaries, delineating pits and trenches containing metallic and nonmetallic debris, and locating buried pipes, drums, and UST's.

2.2 SURVEY CONTROL

Survey control was established at the Barnes Creek site using a 300-foot fiberglass tape and surveyor's paint to mark 10-foot stations along the GPR signal test lines and the primary 1,500-foot survey line. Wooden survey stakes were placed on 100-foot centers along the 1,500-foot survey line and labeled with local coordinates. At Site 3A, the existing survey stations along p-wave seismic Line 5A were utilized for GPR positioning.

Once the survey lines were established and control points were marked, detailed hand-sketched profile maps of each site were drawn in the field. The maps included any surface topographical features, changes in vegetation cover, or cultural features (e.g., fences and overhead utilities) along or near the GPR survey lines that could potentially affect the geophysical data. The maps also included reference features, such as the woods line, gravel access roads, and utility poles that could later aid in reconstructing the line locations. All pertinent reference information documented on the hand-sketched site maps was translated to aerial photographs and plan-view maps of the sites.

2.3 SIDESWIPE REFLECTION TEST

As a measure of quality assurance (QA), sideswipe reflection testing was performed with the 200- and 100-MHz antennas along two orthogonal profiles located near the woods line at Barnes Creek. The test was conducted to determine the potential effects of the nearby trees and overhead utility lines on the recorded GPR signal. For mapping potentially subtle targets, such as those representing near surface faults, the presence of sideswipe or "out-of-the-plane" signal reflections from nearby objects could either mask the primary reflections from the faults or be misinterpreted as diffractions from the faults. The GPR sideswipe test results are presented as **Figures 1-3**. Other than a reflection caused by the overhead utility line at approximate station 80NE on Line SW-NE **(Figure 2)**, no sideswipe reflections were evident in the test data.

2.4 PRODUCTION PROCEDURES

Initially, GPR system optimization testing was performed by varying antenna frequency, depth range, and signal amplitude gain and filter settings to determine system parameters best suited for site subsurface conditions. (At Barnes Creek, the 200-, 100-, 80-, and 16-MHz antennas were used along the survey line; the 200- and 40-MHz antennas were used at Site 3A.) Once established, these parameters were used for the duration of the survey.

A total of approximately 10,600 linear feet of GPR survey data were collected during the GCS at both sites. GPR data were recorded semicontinuously at 32 scans per second as the 200- and 100-MHz antennas were hand towed along the survey lines. GPR data representing common midpoint stations were acquired with the 80-, 40-, and 16-MHz bistatic antennas as they were advanced from station to station. The transmitter (Tx) / receiver (Rx) separation used for the 80-MHz antenna was 5 feet; the Tx/Rx separation used for the 40- and 16-MHz antennas was 10 feet. Data file names were recorded on the data file tracking form. Data were viewed in real-time on the GPR system color monitor and printed in real time with a DPU-5400 high-resolution thermal gray-scale printer.

Following the investigation, GPR data were downloaded to a personal computer, backed up on compact disks (CD), and are retained in project files.

3.0 DATA PROCESSING

GPR calibration study data were processed using Radan® for Windows NT software from GSSI. The level of processing of each GPR profile varied depending on the benefit to the overall data interpretation. Select profiles were color-enhanced to aid in interpretation of subtle anomalies, whereas others are presented in the grayscale "field form" with frequency spectra shown.

Prior to signal processing, the GPR data were screened so that line and station ranges and overall data quality could be assessed. The names of the files generated and processing parameters used were recorded on data processing forms. All completed data acquisition and processing forms and original plotted sections collected during the investigation are retained in project files.

The general processing flow included importing the .DZT files into Radan®, running the frequency spectra module to determine the dominant frequency recorded for site-specific conditions, then selecting a grayscale color transform to maximize the signal to noise (S/N) ratio and reflected events.

Enhanced signal processing was performed on a portion of the 200-, 100-, and 80-MHz data representing the Barnes Creek site to provide for a more accurate subsurface interpretation. The following processing sequence was used for these data:

- Data Import into Radan®;
- Color Amplitude Design;
- Vertical Position Correction;
- Finite Impulse Response Filtering;
- 2D Frequency-Wavenumber (F-K) Filtering;
- Exponential Gain;
- Predictive Deconvolution; and
- Exponential Gain.

4.0 RESULTS

Figures 1-20 represent the GPR profile data acquired during the GCS. The profiles depict horizontal distance in feet versus two-way traveltime. Depths described herein have been estimated from the approximate relationship of 1 foot of depth per 7 nanoseconds (ns) of two-way traveltime. This standard relationship is found in EM wave velocity tables for various earth materials. The specific value chosen was based on near-surface soil characteristics observed at the sites.

The GCS data quality results vary significantly between Barnes Creek and Site 3A, and also depending on which antenna was used to acquire the data. At Barnes Creek, data acquired with the 200-MHz antenna **(Figure 18B)** show good detail to a depth of approximately 10-12 feet below ground surface (bgs); however, 200-MHz data acquired at Site 3A **(Figure 15)** show relatively poor resolution and a maximum signal penetration depth of approximately 5 feet bgs. The difference in data quality and resolution is likely due to differences in soil types comprising the near surface at both sites. The near-surface soils at Barnes Creek are likely more granular and contain lesser amounts of clay, although this could not be confirmed by intrusive sample results at the time of this writing. Data acquired with the 100-MHz antenna at Barnes Creek **(Figure 8)** also show a lack of signal penetration and poor resolution. Data acquired with the 80-MHz antenna at Barnes Creek **(Figure 12)** show a significant and generally flat reflection at approximately 95 ns. However, the general lack of other significant reflections combined with minimal incoherent noise in the section and the anomalously flat nature of the observed anomaly, indicates the feature is most likely caused system noise rather than a deep flat-lying geologic unit. Similar arguments can be made for the strong reflector occurring at approximately 90 ns in the 16-MHz data **(Figure 13)** at Barnes Creek and at approximately 100 ns in the 40-MHz data representing Site 3A **(Figure 17)**.

The most prominent geophysical anomalies identified in the GCS data are seen in the 200-MHz Barnes Creek data. The anomalies occur as two zones of significant near-surface disturbance relative to background conditions. The anomalies are most apparent at approximate stations 1140W and 1330W in **Figures 6 and 18B**. Anomalous primary reflections from an approximate depth of 1-2 feet bgs are clearly evident in **Figure 18B**. The locations of these anomalies are roughly aligned with the northward projection of faults seen in the creek banks along Barnes Creek approximately 150 feet to the south. At Site 3A, the most significant deep reflections in the 200-MHz data **(Figure 15)** occur from approximate stations 700N-740N. This anomaly is evident from approximately 100-120 ns and interpreted to be caused by surface reflections from a nearby utility pole anchor line and a chainlink fence. In the Site 3A 40-MHz data **(Figure 17)**, the most prominent reflections occur at approximately 100 ns and thought to be caused by internal GPR system noise.

5.0 REFERENCES

BJC (Bechtel Jacobs Company, LLC), 2001, "*Seismic Assessment Plan for Siting of a Potential On-Site CERCLA Waste Disposal Facility at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, BJC/PAD-207 (Final), September.

Keller, G. V. and F.C. Frischknecht, 1966, Electrical Methods in Geophysical Prospecting, International Series in Electromagnetic Waves, Volume 10, Pergamon Press, Oxford, England.

Ulriksen, C.P.F., 1982, Application of Impulse Radar to Civil Engineering, Department of Engineering Geology, Lund University of Technology, Sweden.

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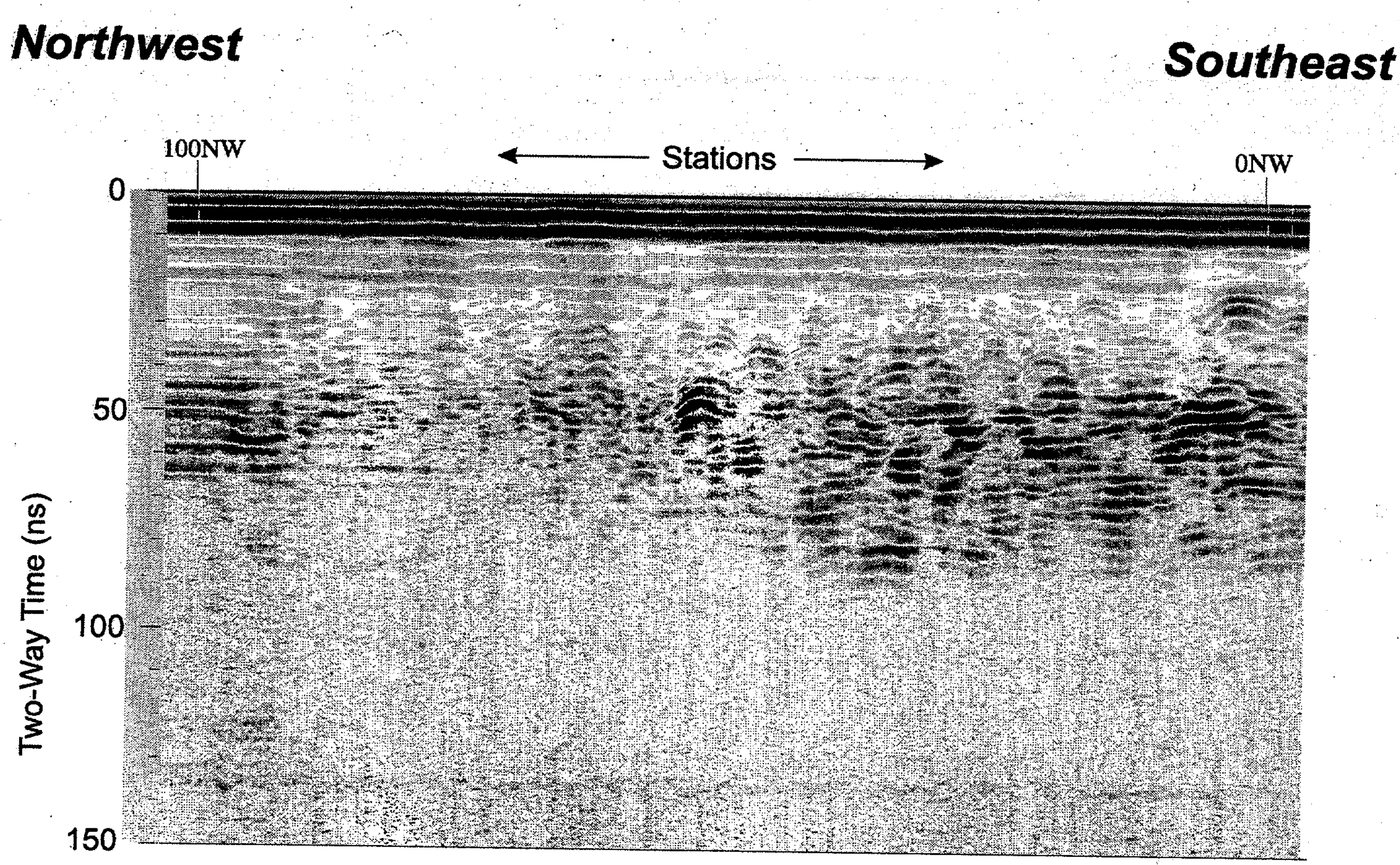
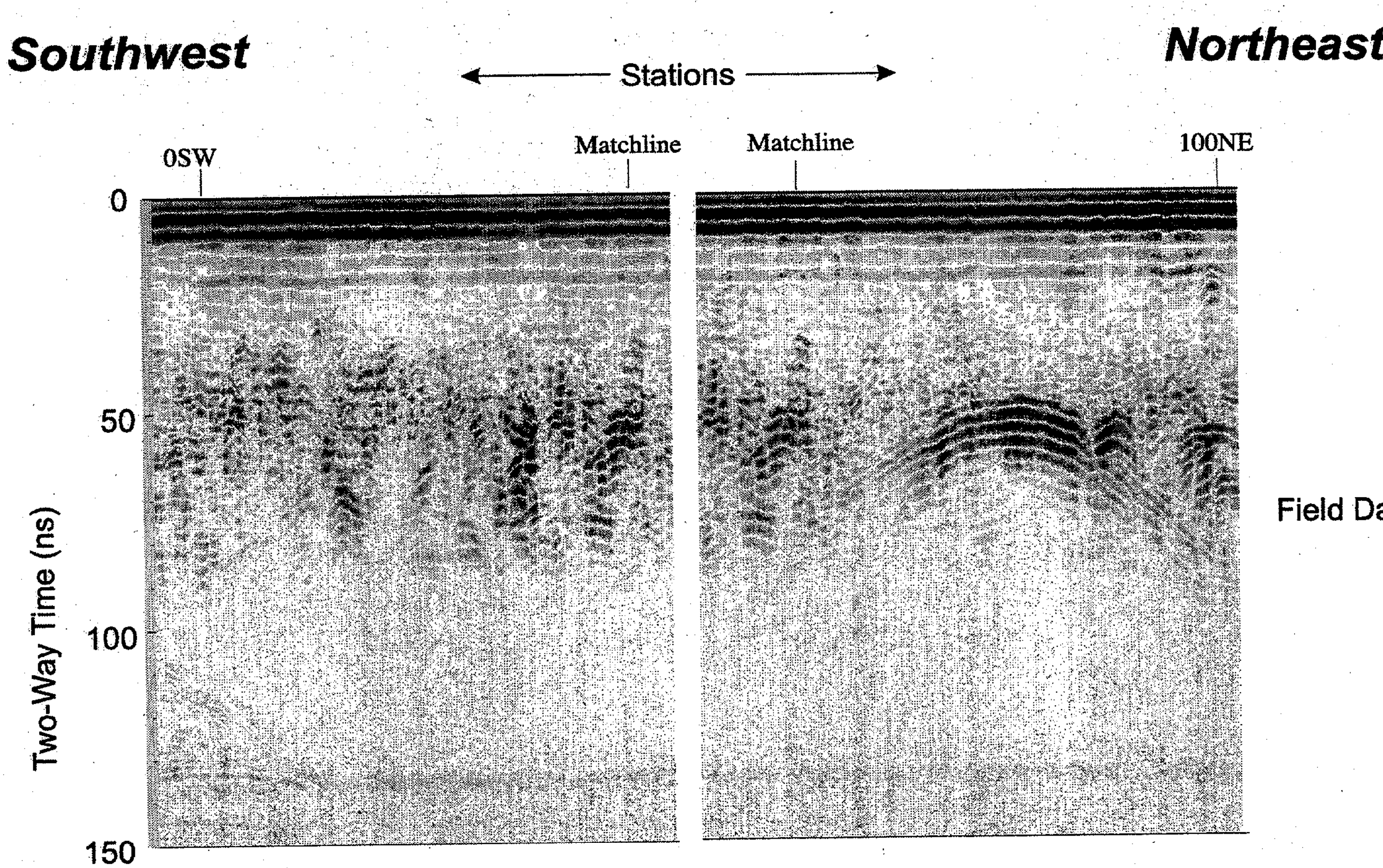
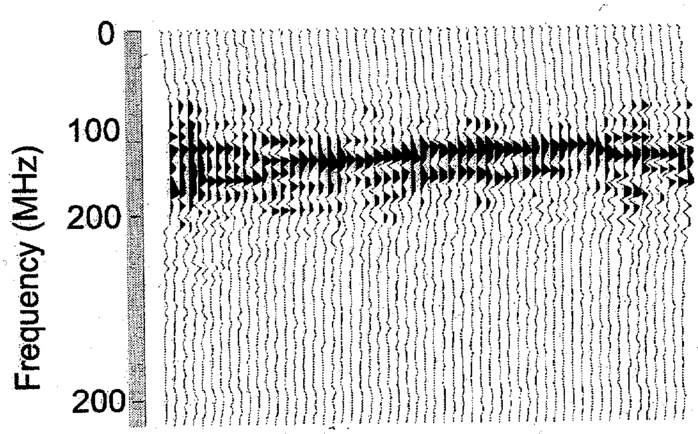


BLACKHAWK GeoServices Southeast Region	SAIC Oak Ridge, Tennessee
Figure No. 1	Line NW-SE GPR Signal Sideswipe Test 200-MHz Antenna Illinois Farm Site
Project No. 2901SAI	
File No. 2901saiFile66_A.cdr	
Date: Jan., 2002	



Field Data

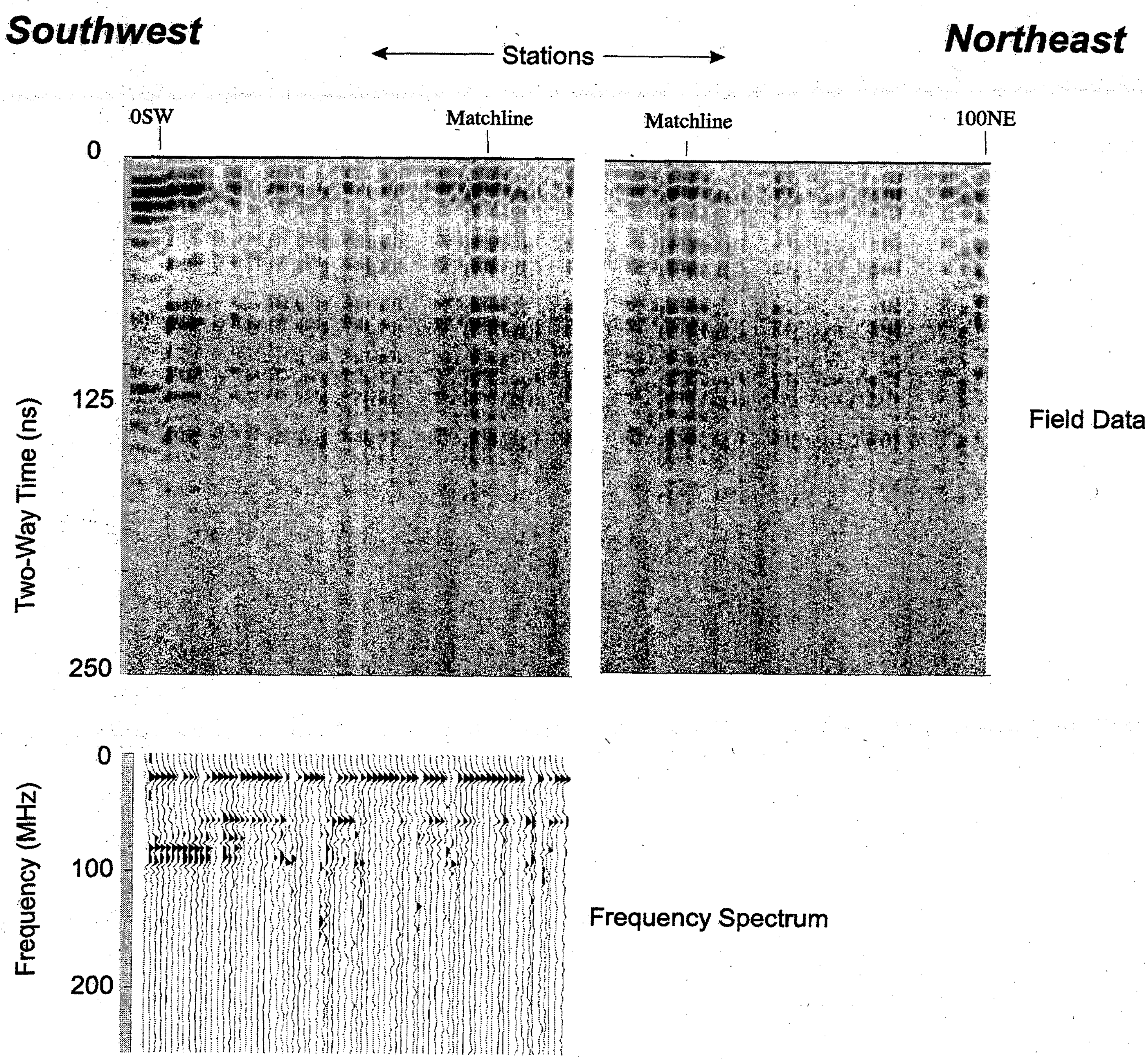


Frequency Spectrum

BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 2	**Line SW-NE GPR Signal Sideswipe Test 200-MHz Antenna**
Project No. 2901SAI	
File No. *2901sai\File67_A.cdr*	Illinois Farm Site
Date: Jan., 2002	



BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 3

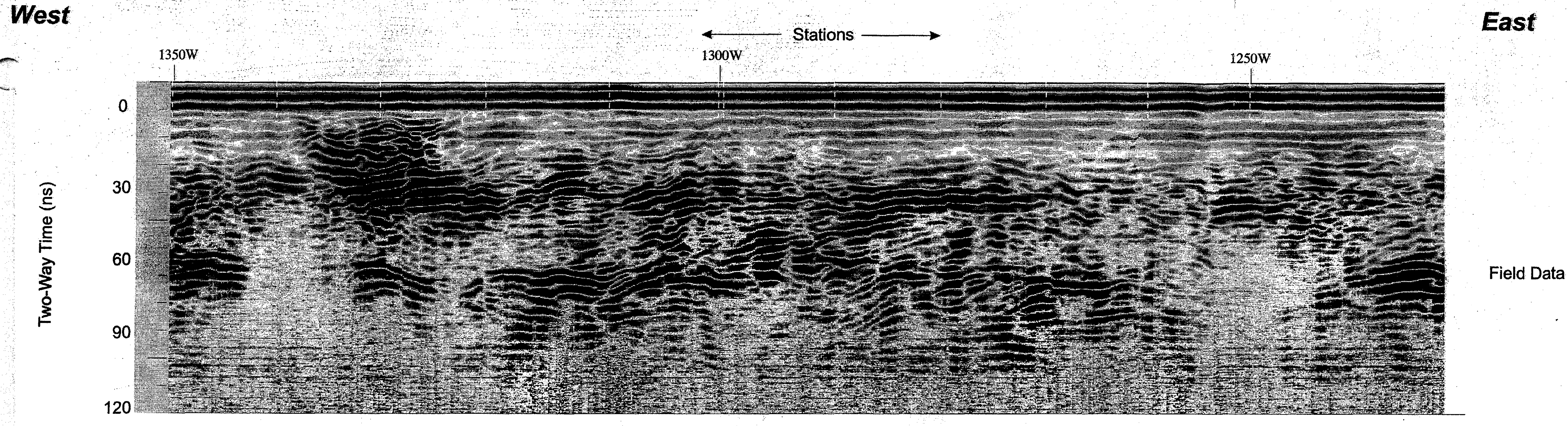
Project No. 2901SAI

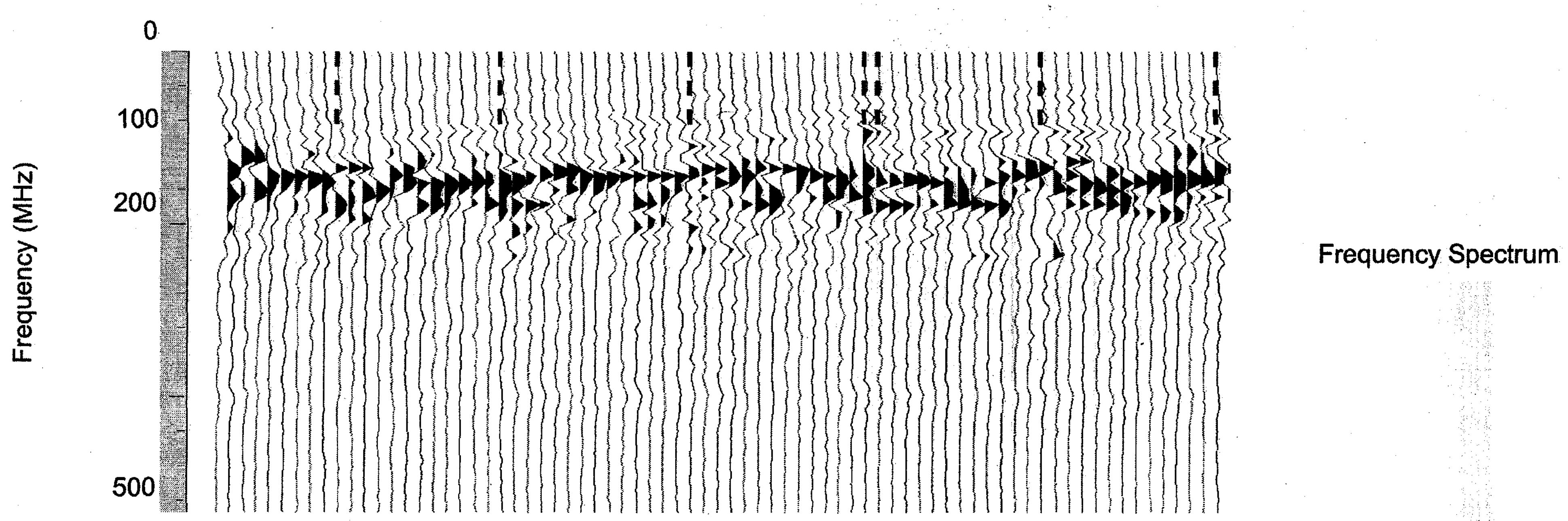
File No. 2901saiFile69_A.cdr

Date: Jan., 2002

Line SW-NE
GPR Signal Sideswipe Test
100-MHz Monostatic Antenna

Illinois Farm Site





BLACKHAWK GeoServices
Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No.
4

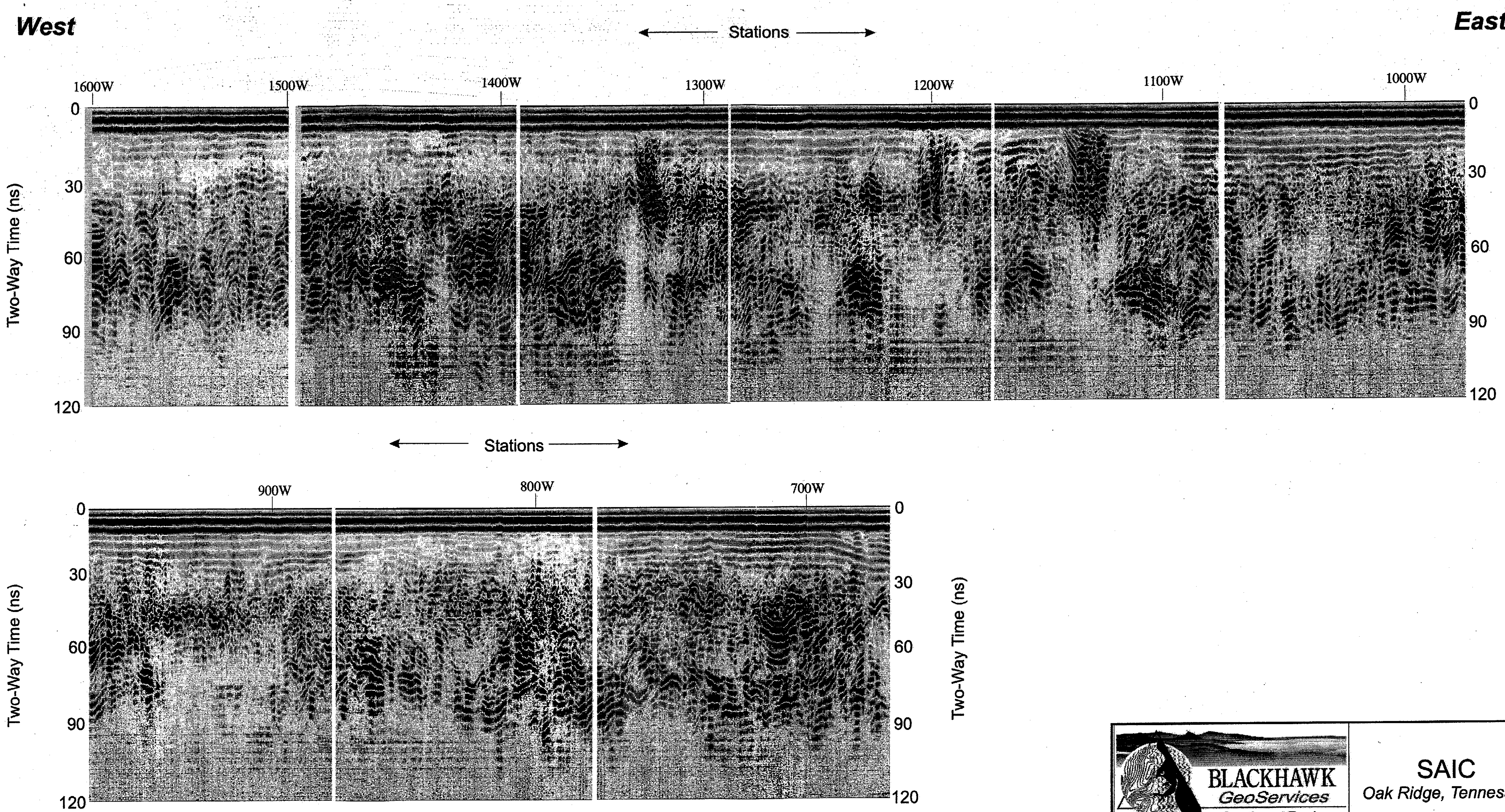
Project No.
2901SAI

File No.
2901sai\File71_sec_B.cdr

Date:
Jan., 2002

Line W-E
GPR Profile Data (1250W - 1350W)
200-MHz Antenna

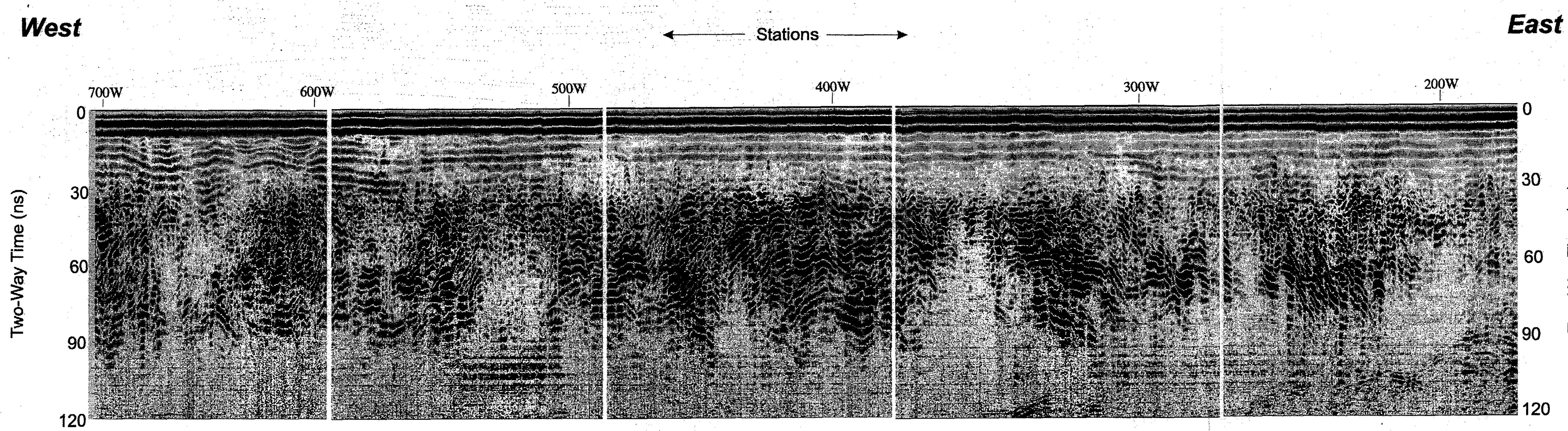
Illinois Farm Site

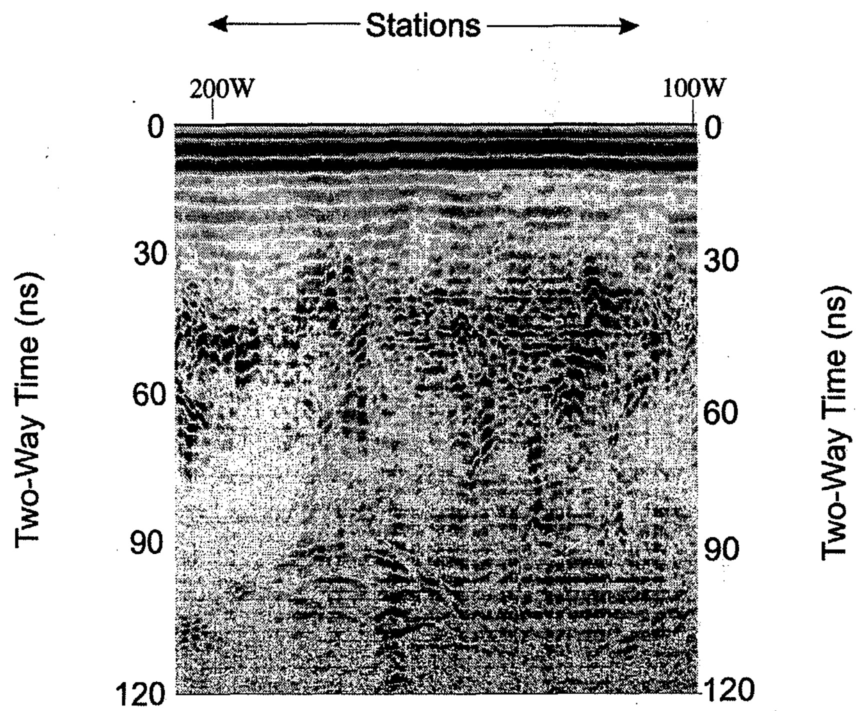


BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 5	**Line W-E** **GPR Profile Data (1600W - 700W)** **200-MHz Antenna** Illinois Farm Site
Project No. 2901SAI	
File No. *2901sai\File71_B.cdr*	
Date: Jan., 2002	

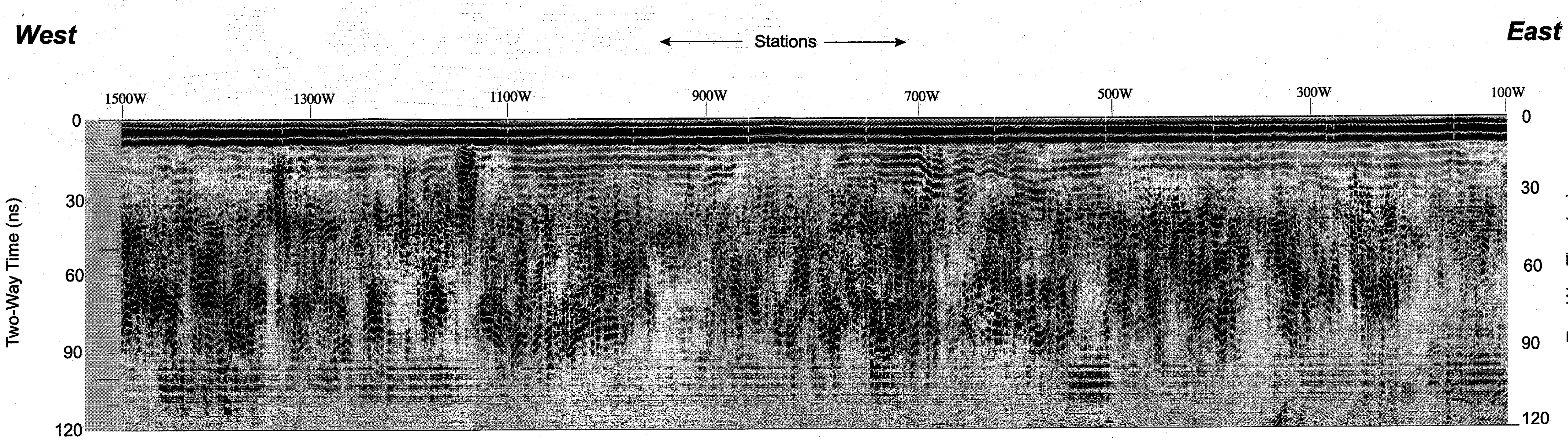




BLACKHAWK GeoServices
Southeast Region

SAIC
Oak Ridge, Tennessee

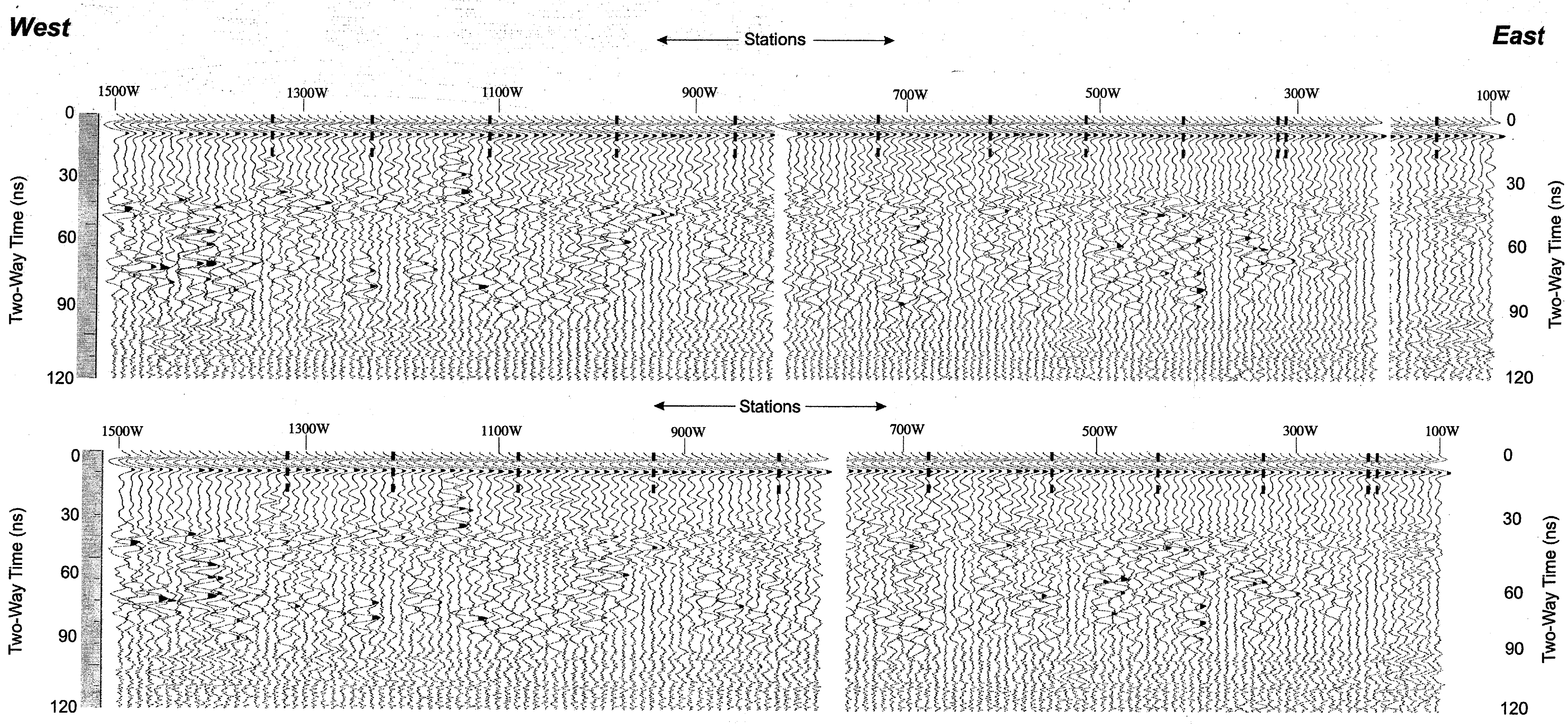
Figure No. 5B	**Line W-E**
Project No. 2901SAI	**GPR Profile Data (700W - 100W)**
File No. *2901sai\File71_B(2).cdr*	**200-MHz Antenna**
Date: Jan., 2002	Illinois Farm Site



BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 6	**Line W-E**
Project No. 2901SAI	**GPR Profile Data (1500W - 100W)**
File No. *2901sai\File71_STK12.cdr*	**200-MHz Antenna (Stack=12)**
Date: Jan., 2002	Illinois Farm Site



BLACKHAWK GeoServices
Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No.
7

Project No.
2901SAI

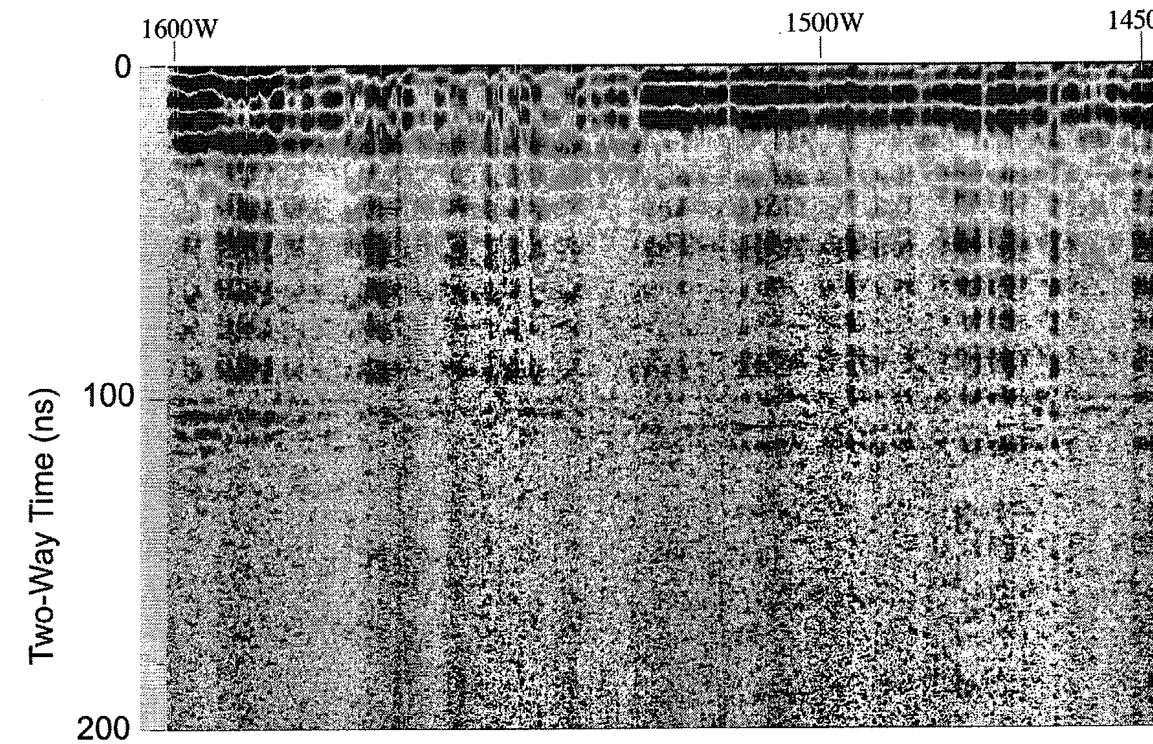
File No.
2901sai\File71_STKDEC12.cdr

Date:
Jan., 2002

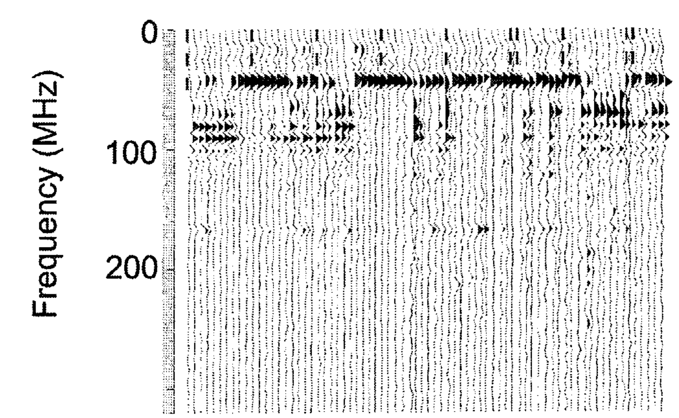
Line W-E
GPR Profile Data (1500W - 100W)
200-MHz Antenna
(Stack=12 vs. Decimated=12)

Illinois Farm Site

West   ← Stations →   *East*



Field Data

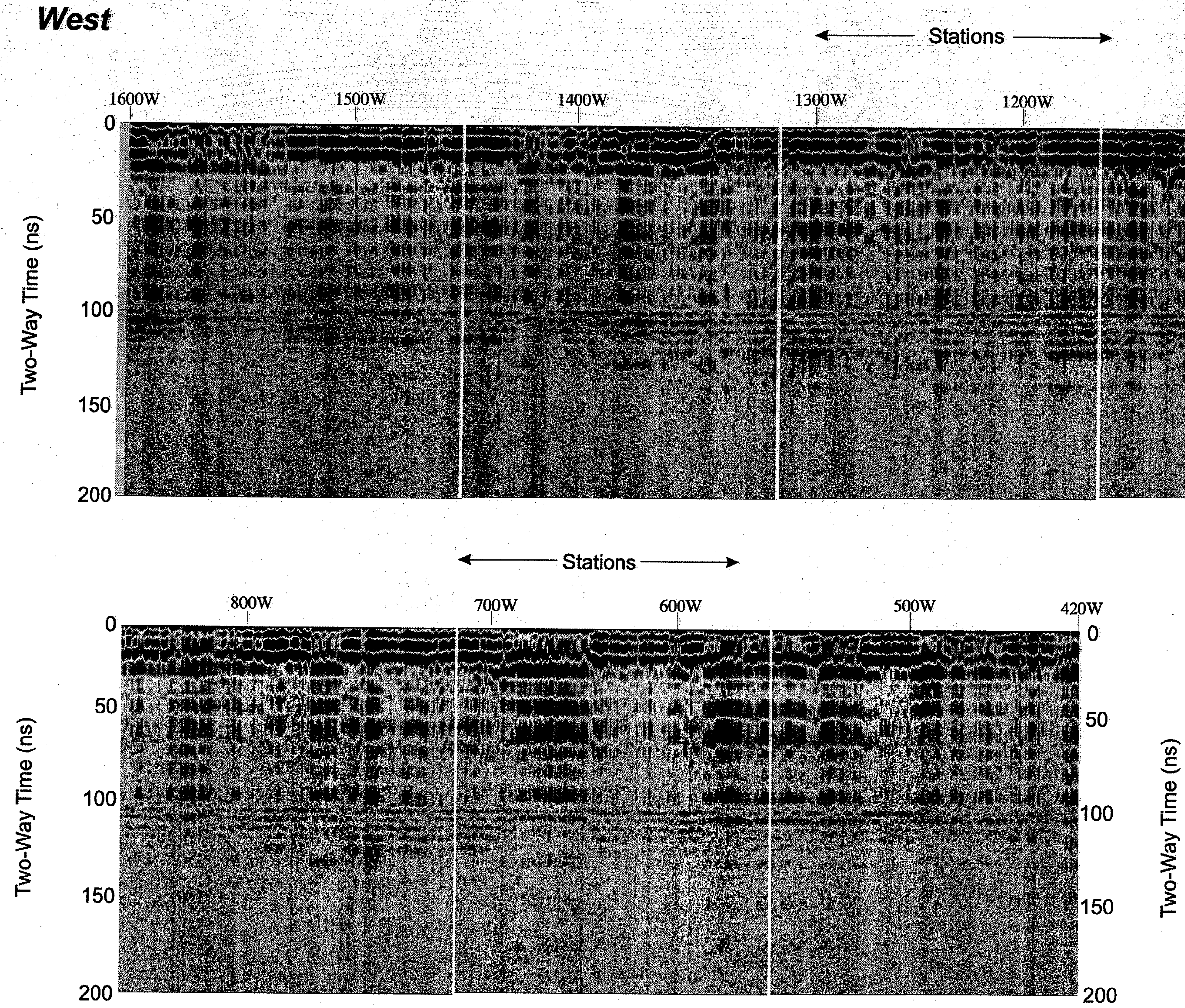


Frequency Spectrum

BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

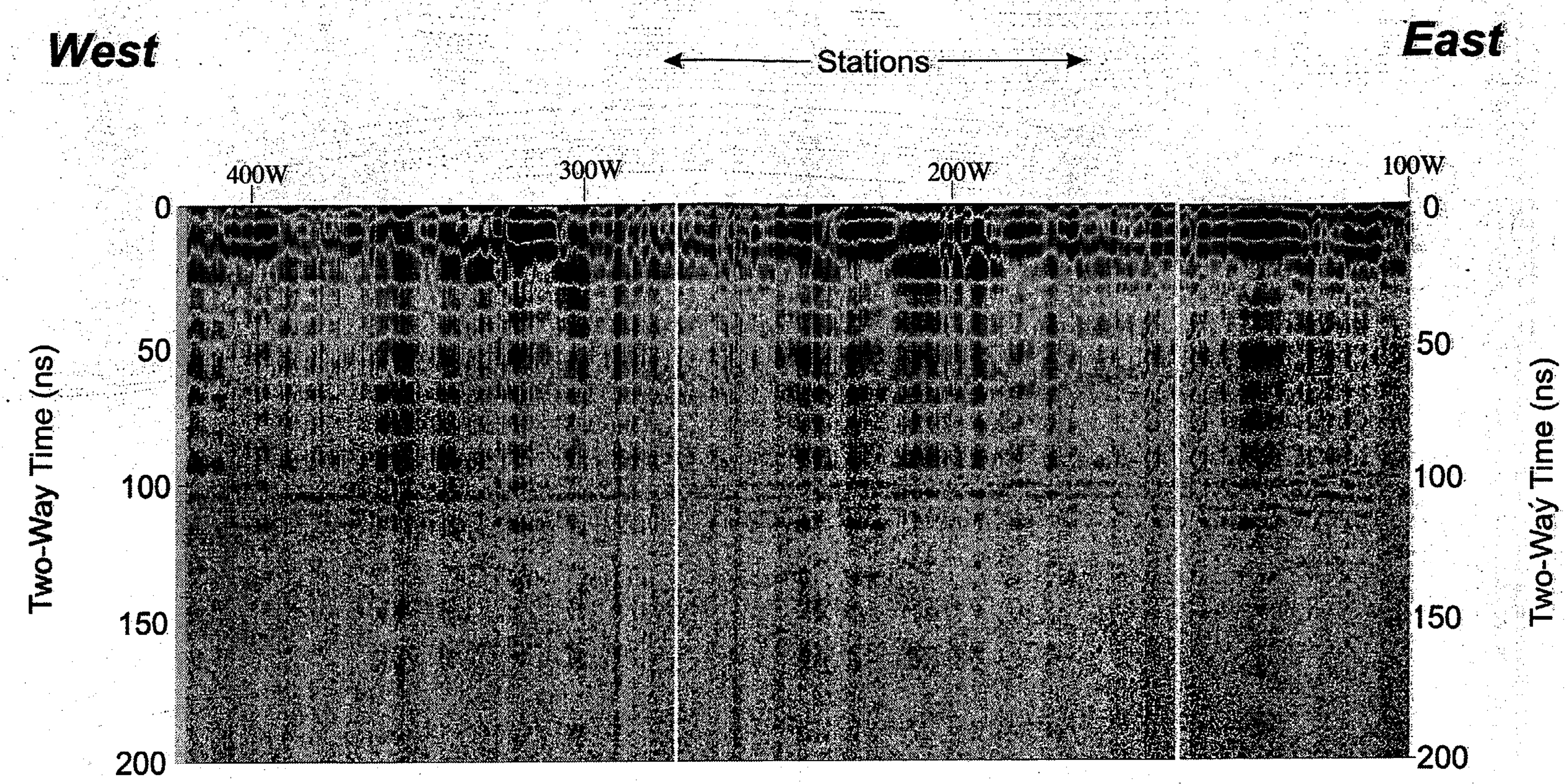
Figure No. 8	**Line W-E**
Project No. 2901SAI	**GPR Profile Data**
File No. 2901saiFile79_A.cdr	**(1450W - 1600W)**
Date: Jan., 2002	**100-MHz Monostatic Antenna**
	Illinois Farm Site



BLACKHAWK
GeoServices
Southeast Region

SAIC
Oak Ridge, Tennessee

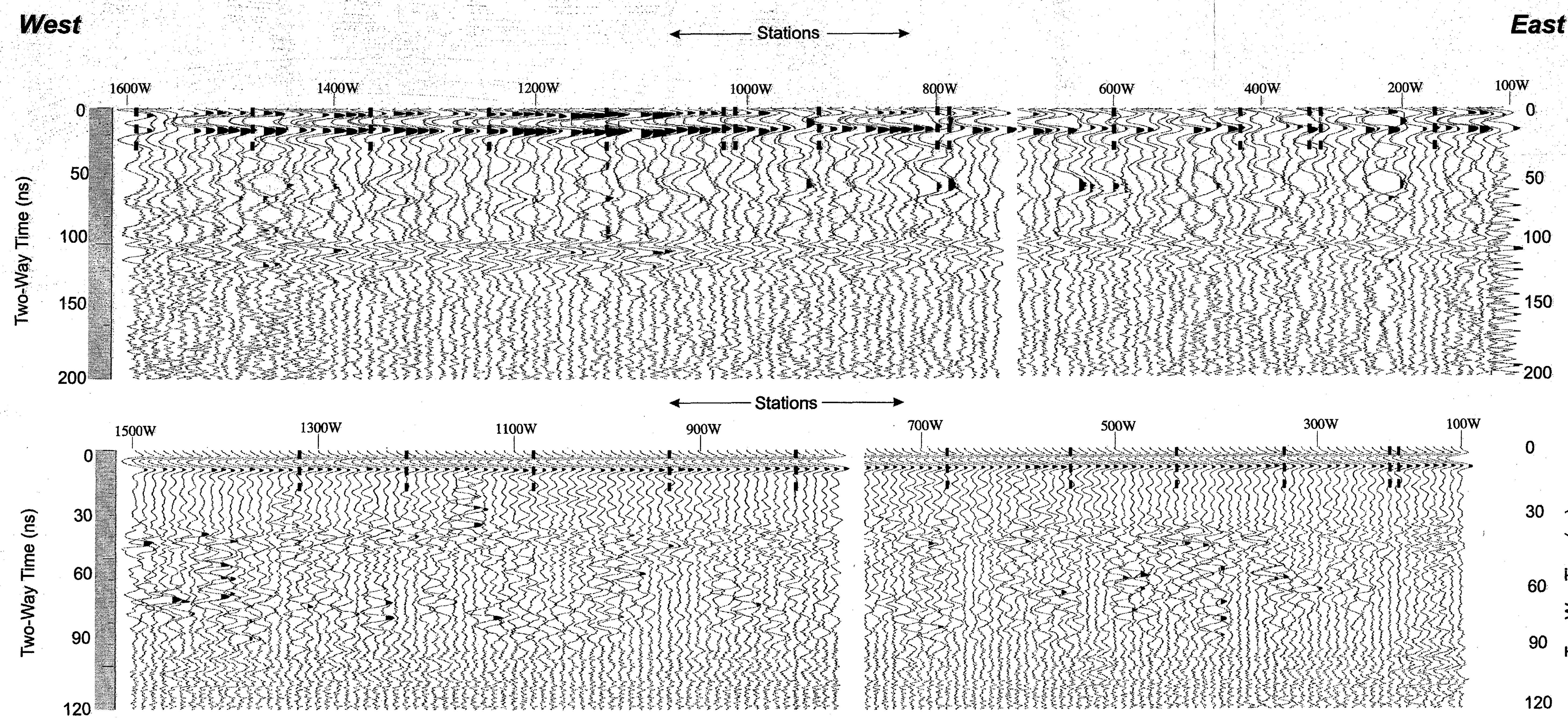
Figure No. 9	
Project No. 2901SAI	**Line W-E** **GPR Profile Data (1600W - 420W)** **100-MHz Monostatic Antenna**
File No. 2901sai\File79_B(1).cdr	Illinois Farm Site
Date: Jan., 2002	



BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

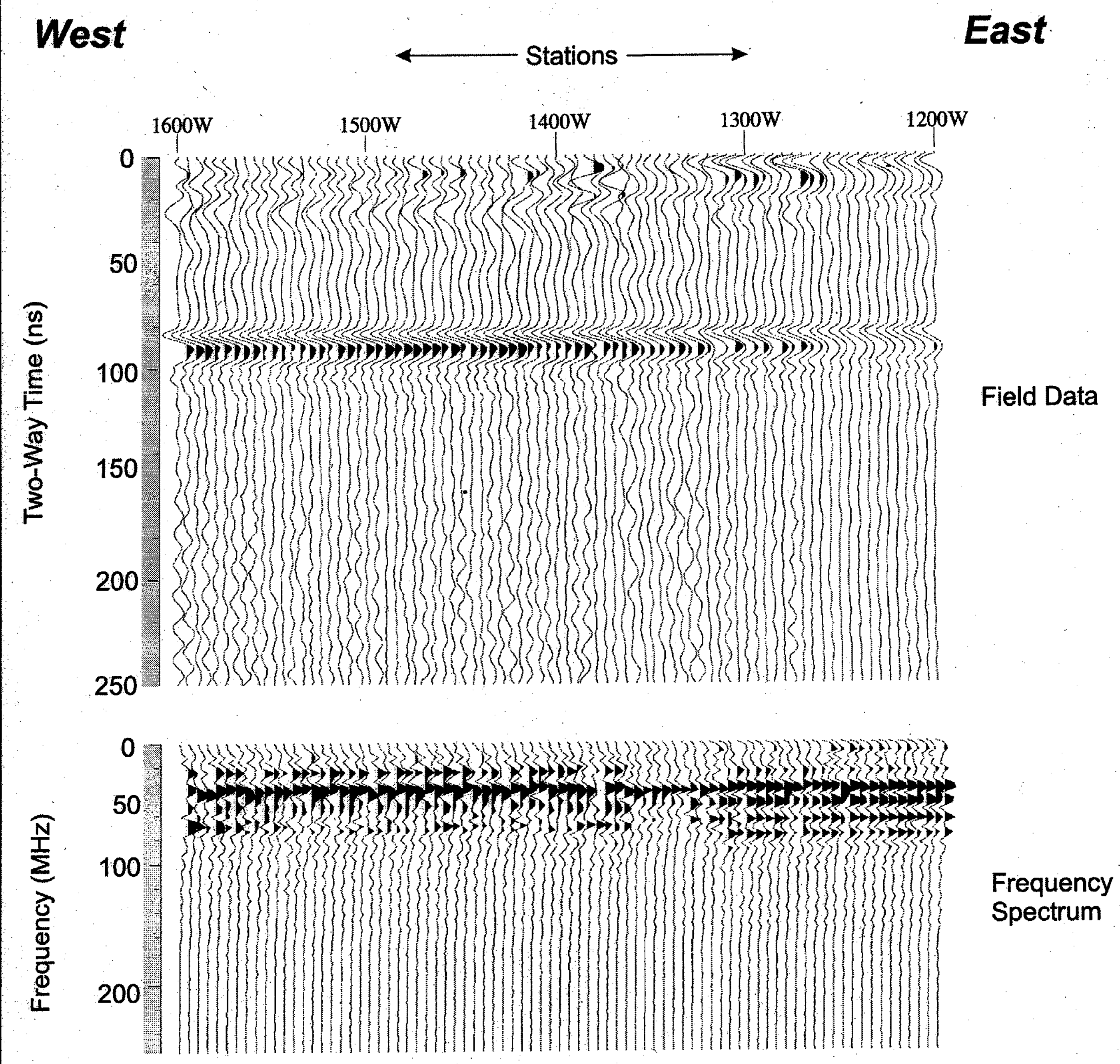
Figure No. 9B	Line W-E GPR Profile Data (420W - 100W) 100-MHz Monostatic Antenna Illinois Farm Site
Project No. 2901SAI	
File No. 2901saiFile79_B(2).cdr	
Date: Jan., 2002	



BLACKHAWK GeoServices
Southeast Region

SAIC
Oak Ridge, Tennessee

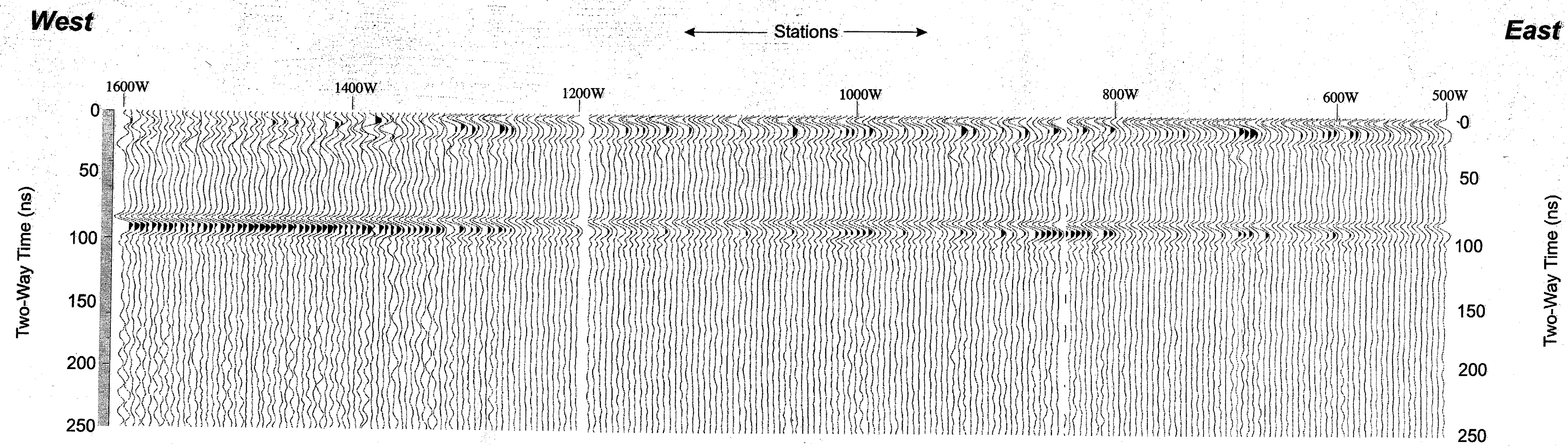
Figure No. 10	**Line W-E**
Project No. 2901SAI	**GPR Profile Data**
File No. 2901sai\File71_79_WIG.cdr	**100-MHz vs. 200-MHz Antenna (Decimated=12)**
Date: Jan., 2002	Illinois Farm Site



BLACKHAWK GeoServices
Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 11	**Line W-E GPR Profile Data (1600W - 1200W) 80-MHz Bistatic Antenna**
Project No. 2901SAI	
File No. *2901sai\File92_A.cdr*	
Date: Jan., 2002	Illinois Farm Site



BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 12

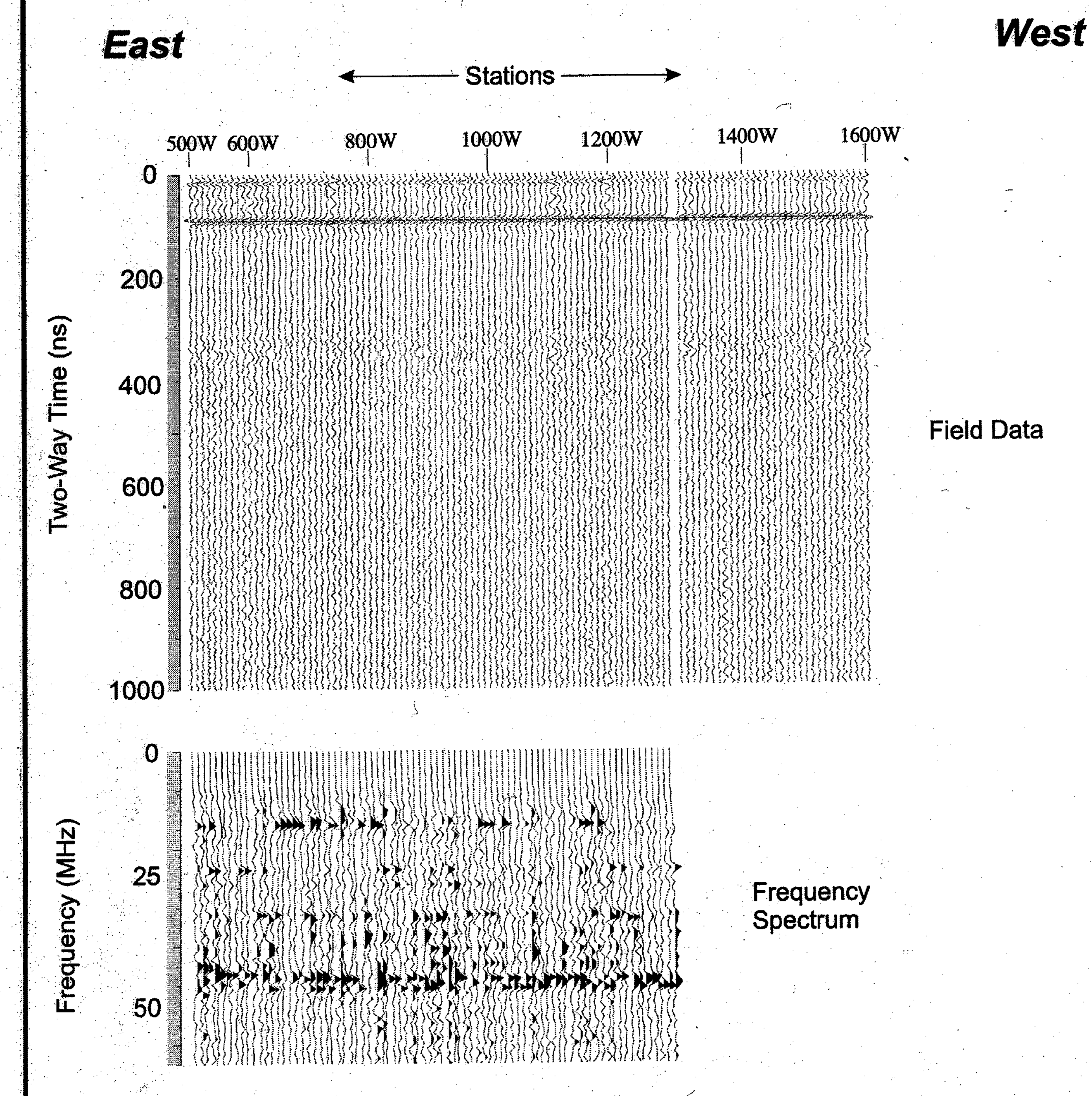
Project No. 2901SAI

File No. 2901sai\File92_B.cdr

Date: Jan., 2002

Line W-E
GPR Profile Data (1600W - 500W)
80-MHz Bistatic Antenna

Illinois Farm Site



BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No.
13

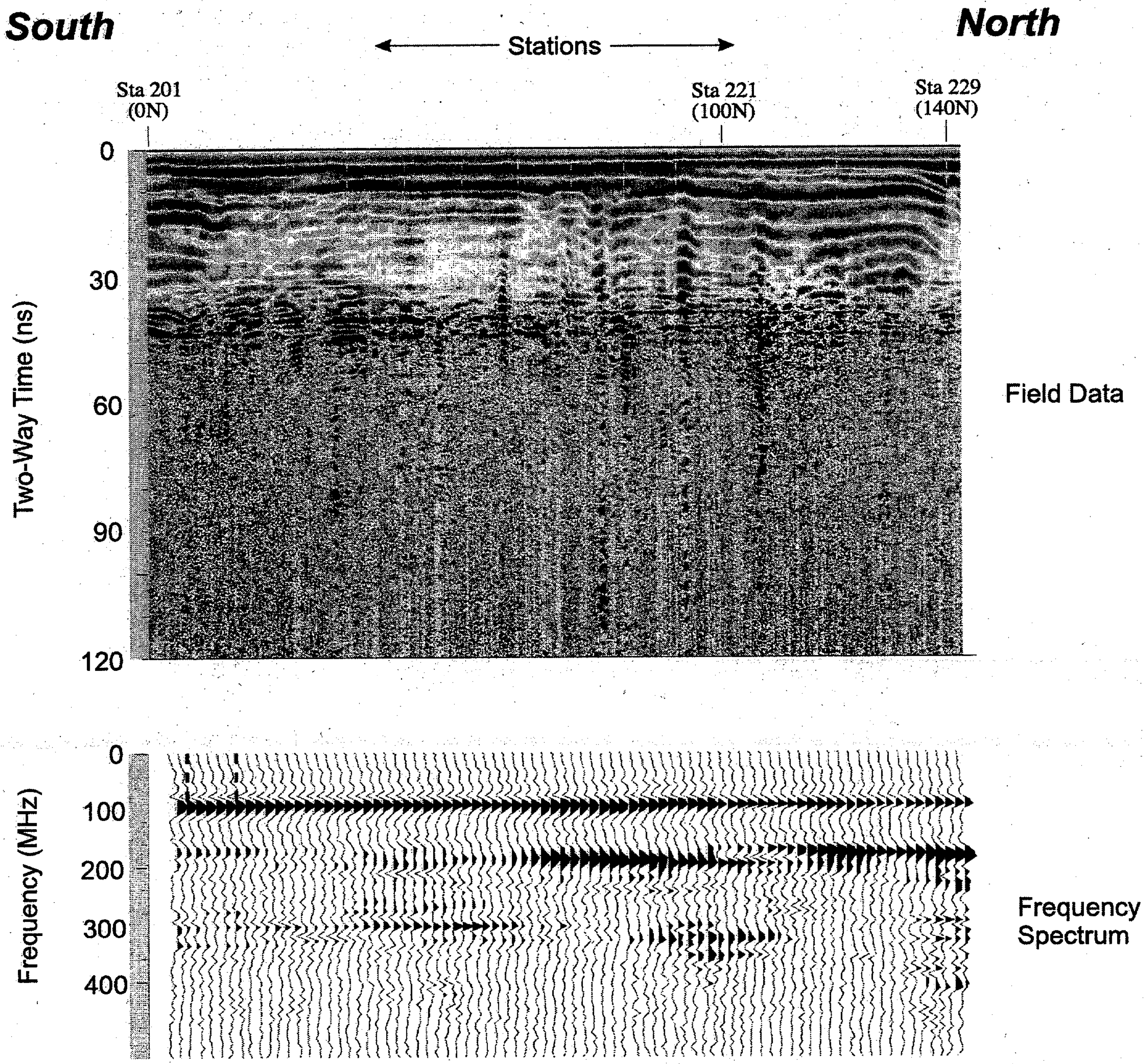
Project No.
2901SAI

File No.
2901sai\File93_A.cdr

Date:
Jan., 2002

Line W-E
GPR Profile Data
(500W - 1600W)
16-MHz Bistatic Antenna

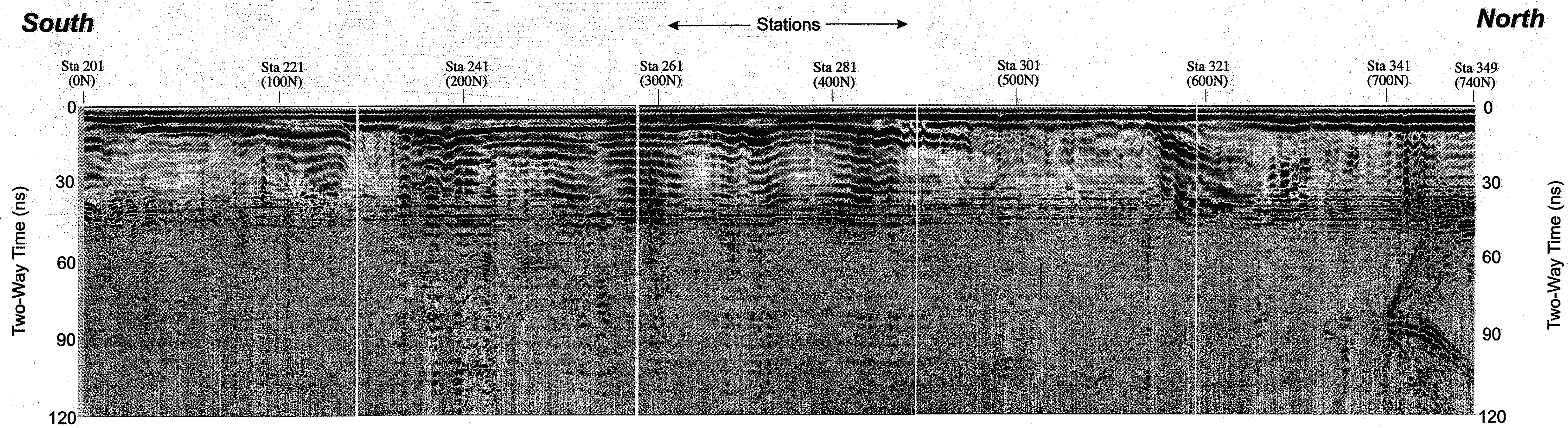
Illinois Farm Site



BLACKHAWK GeoServices
Southeast Region

SAIC
Oak Ridge, Tennessee

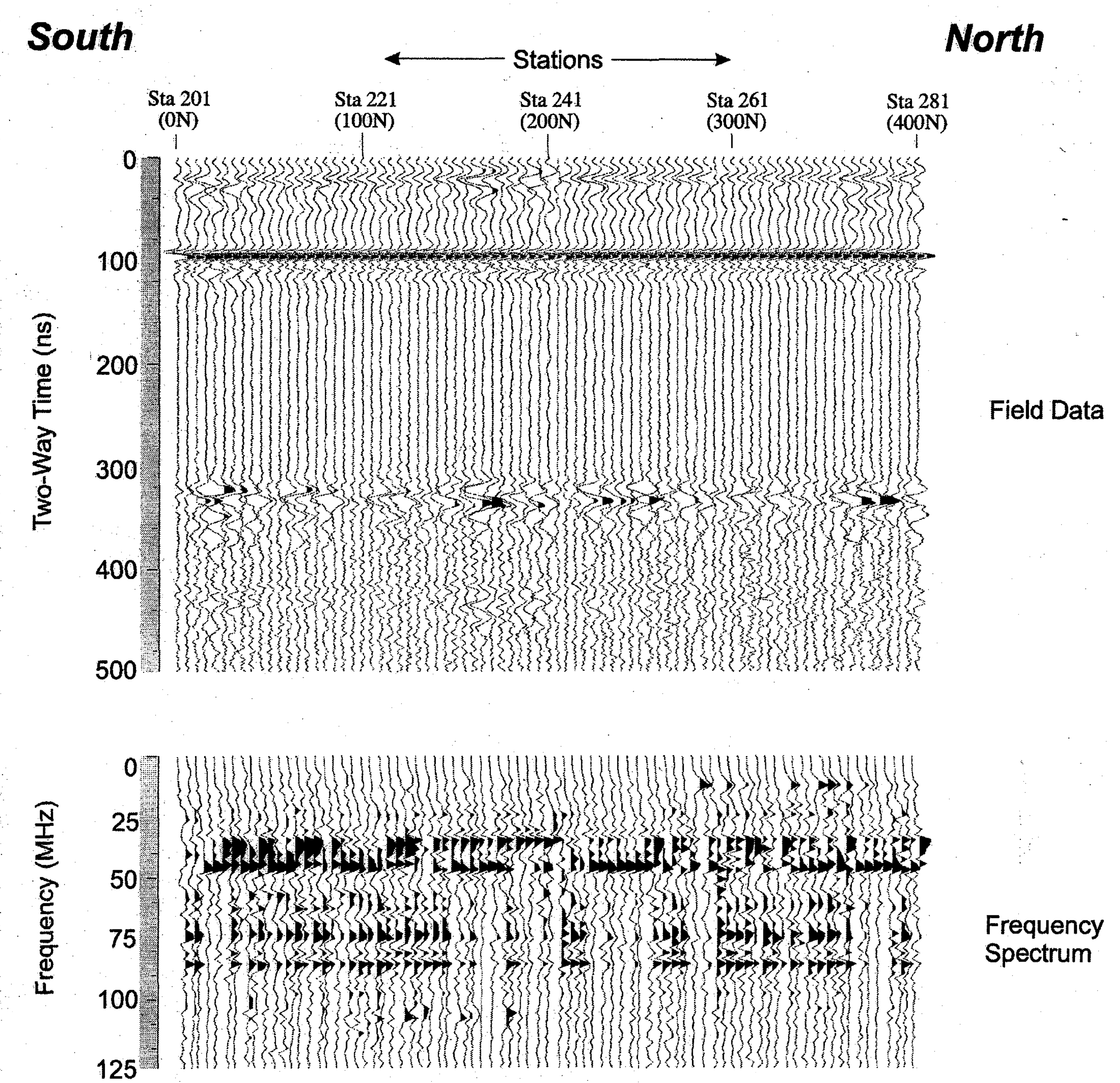
Figure No. 14	**Line 5A, Site 3A GPR Profile Data (Sta 201 - 229) 200-MHz Antenna**
Project No. 2901SAI	
File No. 2901sai\File95_A.cdr	
Date: Jan., 2002	Paducah Gaseous Diffusion Plant



BLACKHAWK GeoServices
Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 15	**Line 5A, Site 3A**
Project No. 2901SAI	**GPR Profile Data (Sta 201 - 349)**
File No. *2901sai\File95_B.cdr*	**200-MHz Antenna**
Date: Jan., 2002	Paducah Gaseous Diffusion Plant



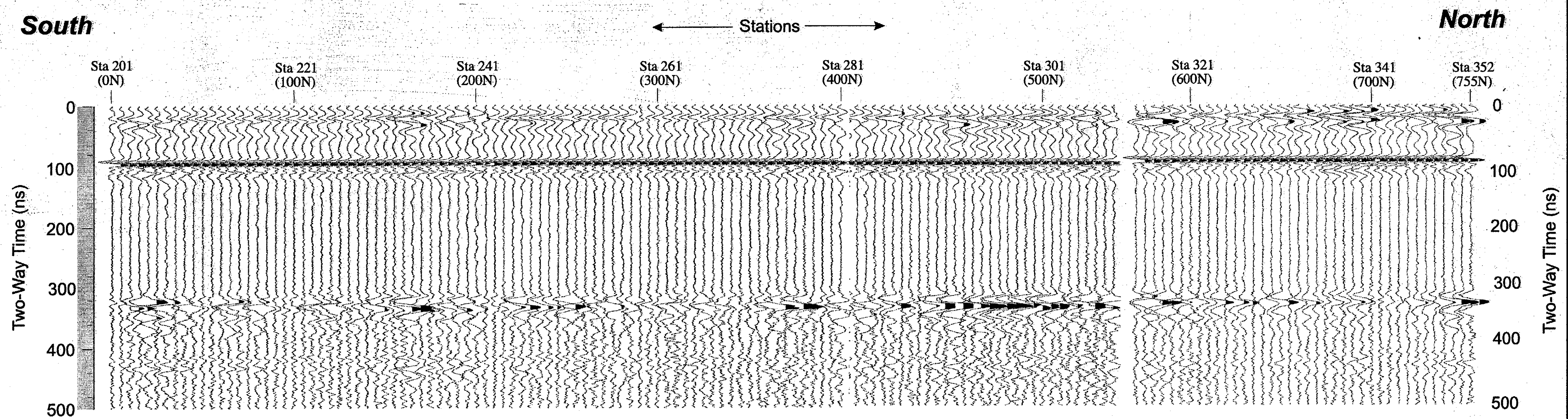
BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 16
Project No. 2901SAI
File No. 2901sai\File98_A.cdr
Date: Jan., 2002

Line 5A, Site 3A
GPR Profile Data
(Sta 201 - 281)
40-MHz Bistatic Antenna

Paducah Gaseous Diffusion Plant

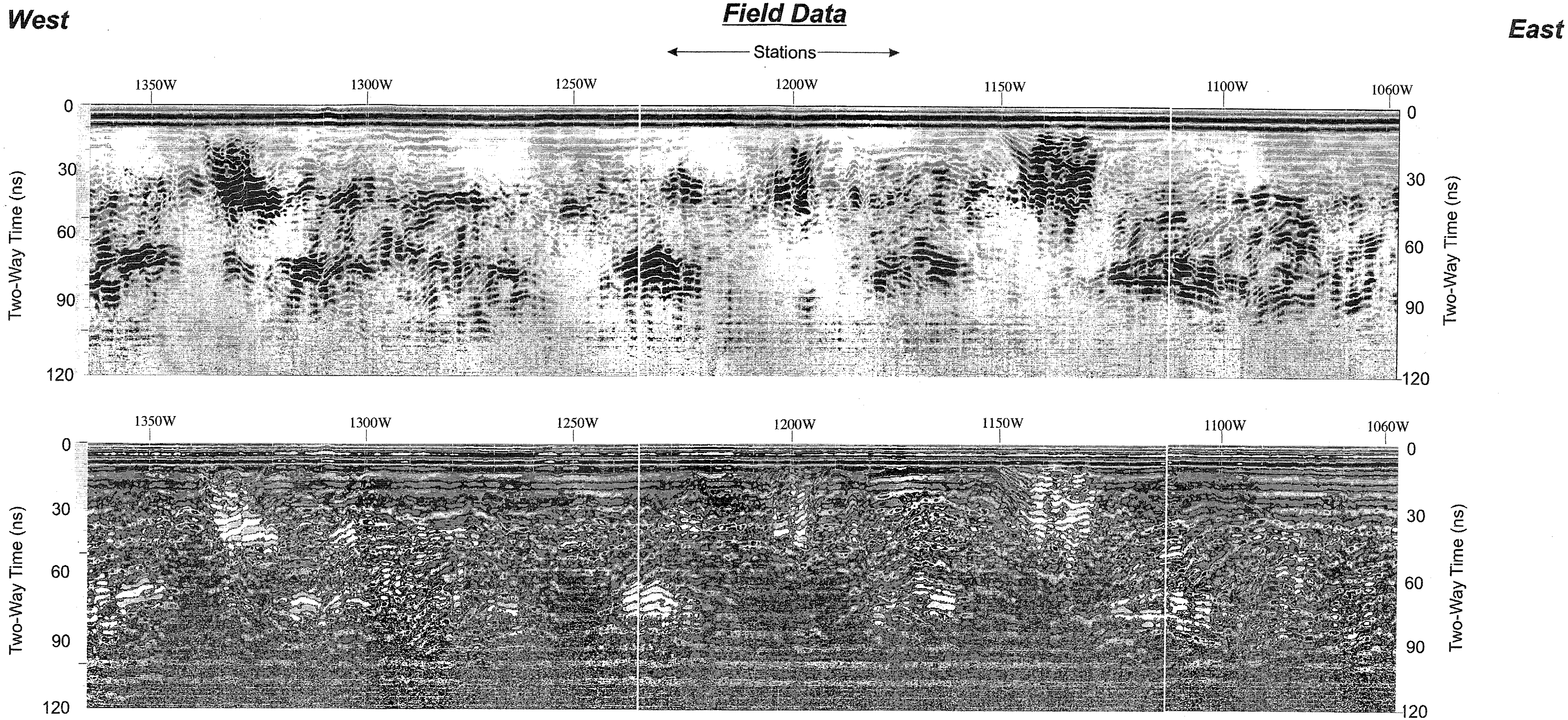


BLACKHAWK GeoServices Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 17	**Line 5A, Site 3A**
Project No. 2901SAI	**GPR Profile Data (Sta 201 - 352)**
File No. 2901sai\File98_B.cdr	**40-MHz Bistatic Antenna**
Date: Jan., 2002	Paducah Gaseous Diffusion Plant

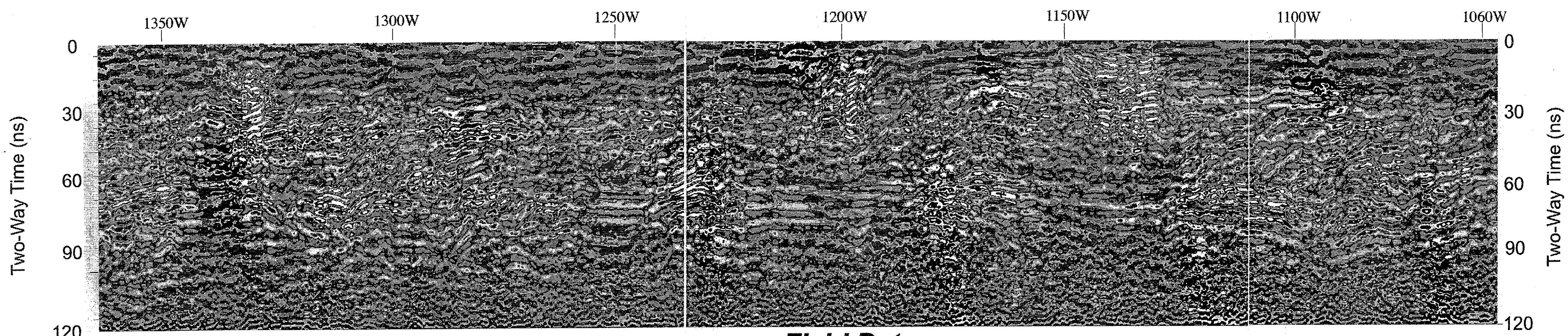
Field Data



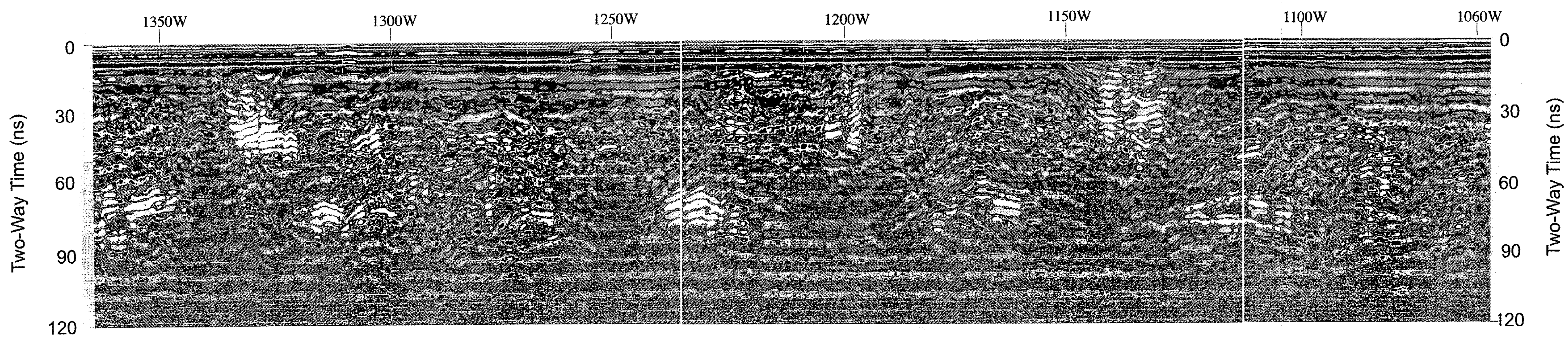
BLACKHAWK GeoServices Southeast Region	SAIC Oak Ridge, Tennessee
Figure No. 18	Line W-E Color-Enhanced GPR Profile Data (1060W - 1360W) 200-MHz Antenna Illinois Farm Site
Project No. 2901SAI	
File No. 2901sai\File71_PROC.cdr	
Date: Jan., 2002	

West **East**

Processed Data



Field Data



Processing Flow:

1. Color Enhancement (CT=2, CX=2)
2. Correct Vertical Position (-5 ns)
3. Finite Impulse Response Filter:
   a. Horizontal High Pass = 511 scans
   b. Vertical High Pass = 150 Mhz
   c. Horizontal Low Pass = 5 scans
4. 2D F-K Filter:
   a. 400-Mhz
   b. Horizontal Symmetric High Cut
   c. Blackman Window
5. Exponential Gain (1.5)

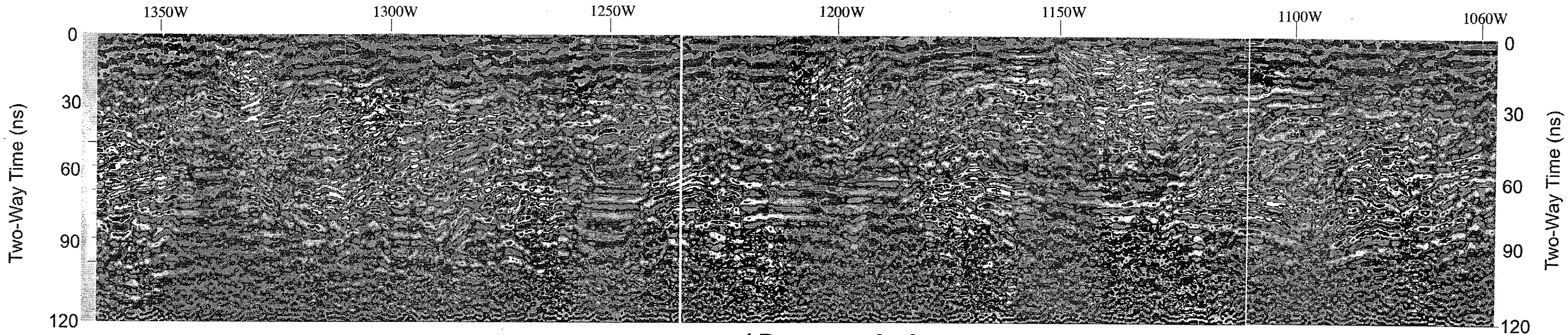
BLACKHAWK GeoServices
Southeast Region

SAIC
Oak Ridge, Tennessee

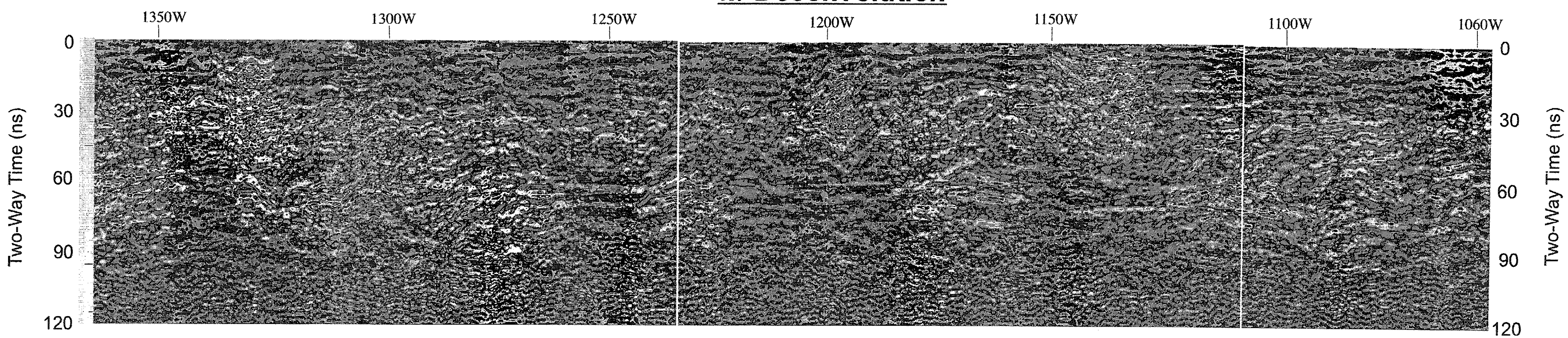
Figure No. 18A	**Line W-E**
Project No. 2901SAI	**Processed GPR Profile Data**
File No. 2901sai\File71_PROC(2).cdr	**(1060W - 1360W)**
Date: Jan., 2002	**200-MHz Antenna**
	Illinois Farm Site

West **East**

Processed Data



w/ Deconvolution



Processing Flow:

1. Color Enhancement (CT=2, CX=2)
2. Correct Vertical Position (-5 ns)
3. Finite Impulse Response Filter:
   a. horizontal high pass = 511 scans
   b. vertical high pass = 150 Mhz
   c. horizontal low pass = 5 scans
4. 2D F-K Filter:
   a. 400-Mhz
   b. horizontal symmetric high cut
   c. Blackman window
5. Exponential Gain (1.5)
6. Deconvolution:
   a. 31 sample operator length
   b. 10% pre-whitening
7. Exponential Gain (3.0)

BLACKHAWK GeoServices
Southeast Region

SAIC
Oak Ridge, Tennessee

Figure No. 18B	**Line W-E**
Project No. 2901SAI	**Processed GPR Profile Data**
File No. 2901saiFile71_PROC(3).cdr	**(1060W - 1360W)**
Date: Jan., 2002	**200-MHz Antenna**
	Illinois Farm Site

APPENDIX D

TECHNICAL MEMORANDUM FOR THE SITE-SPECIFIC FAULT STUDY FOLLOW-UP ACTIVITIES

Prepared by
SAIC Engineering, Inc.
151 Lafayette Drive
Oak Ridge, TN 37830

August 2002

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CONTENTS

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FIGURES

TABLES

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ACRONYMS

BJC	Bechtel Jacobs Company LLC
^{14}C	carbon-14
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	U.S. Department of Energy
DPT	direct-push technology
EPA	U.S. Environmental Protection Agency
GPR	ground-penetrating radar
p-wave	compression (P) wave
PGDP	Paducah Gaseous Diffusion Plant
s-wave	shear (S) wave

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1. INTRODUCTION

Representatives and support staffs of the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the Commonwealth of Kentucky, worked together to develop a field investigation program to address seismic issues associated with potentially siting a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) waste disposal facility at the Paducah Gaseous Diffusion Plant (PGDP). These planning efforts for conducting the Seismic Investigation program at Site 3A are described in the *Seismic Assessment Plan for Siting of a Potential On-Site CERCLA Waste Disposal Facility at the Paducah Gaseous Diffusion Plant* (BJC 2001) and an evaluation of National Environmental Protection Act values (BJC 2002). Site 3A consist of 110 acres situated immediately south of the PGDP security fence (Fig. D.1). The Seismic Investigation Program consisted of three primary tasks: a Paleoliquefaction Study, a Fault Study, and a Geotechnical Study. These three tasks are documented in five technical memoranda.

The Fault Study was comprised of two components, a regional Fault Study and a site-specific Fault Study. The site-specific Fault Study was conducted in two phases: the "initial activities" and the "follow-up activities." The initial activities, which are documented in a separate technical memorandum (SAIC 2002), indicated the possibility of "shallow" faulting (i.e., potential deformation of the Porters Creek Clay). As a result, DOE, EPA, and the Commonwealth of Kentucky recommended proceeding with follow-up activities (PPC 2002a). This technical memorandum documents the site-specific Fault Study follow-up activities, which included a shear (s-wave) seismic reflection and a direct-push technology (DPT) survey. The originally planned ground penetrating radar (GPR) survey, test pits, and trench were determined to be unnecessary.

2. S-WAVE SURVEY

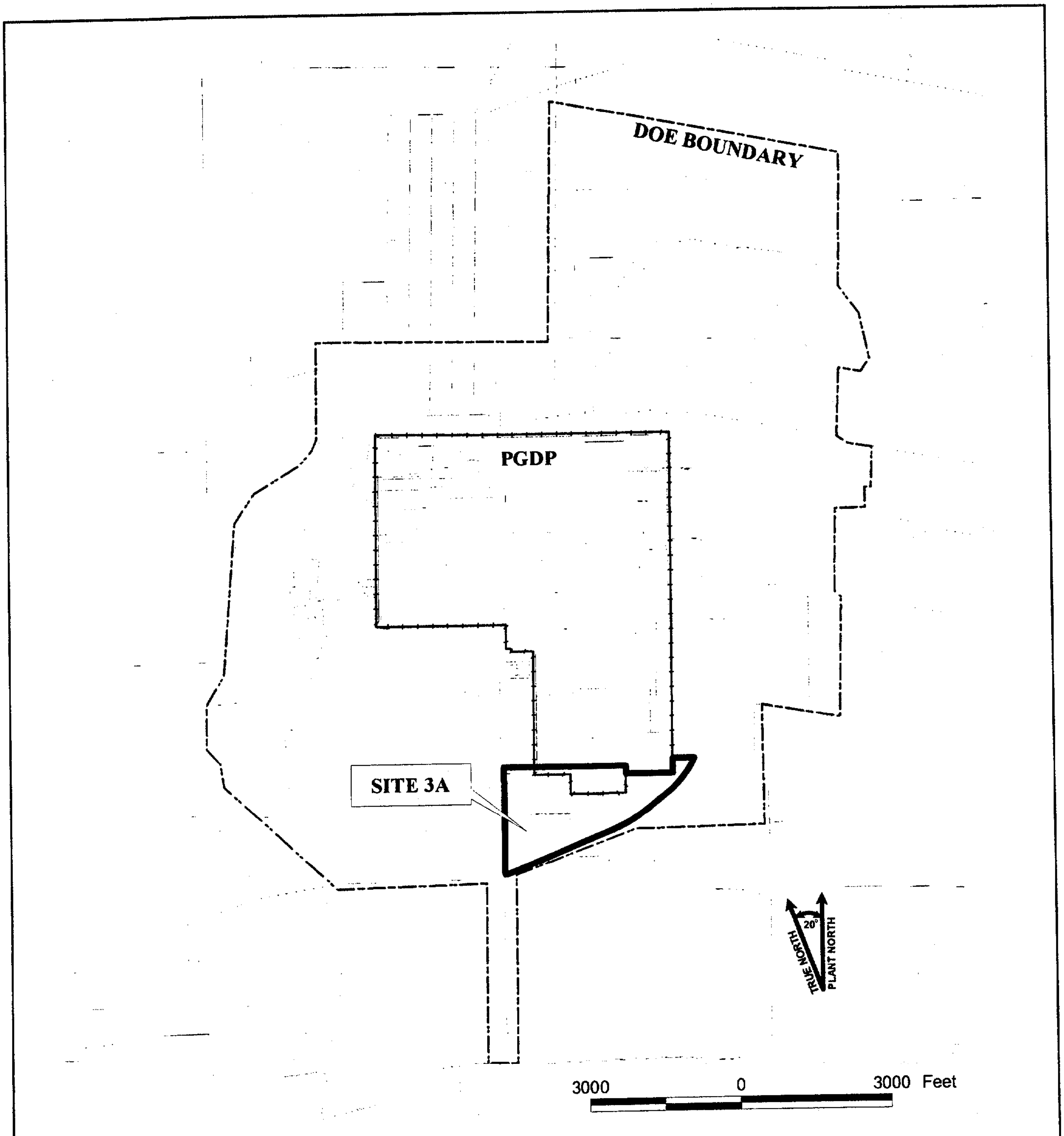
A seismic reflection survey is a nonintrusive geophysical method that uses acoustic energy to image the subsurface; it is used to detect anomalies in the shallow-to-deep subsurface. A summary of this geophysical technique is presented in Attachment D-I of this technical memorandum.

The purpose of the s-wave survey was to determine whether anomalies are present that may suggest the presence of potential shallow faulting at Site 3A. The initial activities included a high-resolution seismic compression (p-wave) survey that identified anomalies, or potential faults, extending from the Mississippian-aged limestone bedrock up into the Paleocene-aged Porters Creek Clay. DOE, EPA, and the Commonwealth of Kentucky met to discuss these results January 15, 2002, and mutually agreed to proceed with the planned follow-up activities, including the s-wave survey (PPC 2002a).

2.1 PLANNED ACTIVITIES

The planned s-wave survey activities are described in Sect. 3.1.3.1 of Part II of the Seismic Assessment Plan as follows (BJC 2001):

> A high-resolution seismic horizontal shear (s) wave reflection survey will be conducted at three locations approximately perpendicular to and intersecting the hypothetical fault. The purpose of this survey is to provide higher resolution data, which may better define potential faulting, from the surface to the top of the Porters Creek Clay, and to refine the locations of the planned intrusive activities (e.g., DPT survey, test pits, and trench). Each of the three lines will be 500 ft long and will use a geophone spacing of 2 m or less…



LEGEND:

FENCE
ROAD
STREAM
DOE BOUNDARY
SITE 3A BOUNDARY

U.S. DEPARTMENT OF ENERGY
DOE OAK RIDGE OPERATIONS
PADUCAH GASEOUS DIFFUSION PLANT

BECHTEL JACOBS COMPANY LLC
MANAGED FOR THE US DEPARTMENT OF ENERGY UNDER US GOVERNMENT CONTRACT DE-AC-05-98OR22700
Oak Ridge, Tennessee • Paducah, Kentucky • Portsmouth, Ohio

Science Applications International Corporation
P.O. Box 2502
Oak Ridge, Tennessee 37831

Fig. D.1. Location of Site 3A.

FIGURE No. c5ac90001sk529.apr
DATE 06-17-02

During the January 15, 2001, meeting, DOE, EPA, and the Commonwealth of Kentucky determined that only two s-wave survey lines would be necessary (PPC 2002a). Immediately following the January 15, 2001, meeting, representatives from DOE and its subcontractors, EPA, and the Commonwealth of Kentucky met to determine the specific locations and lengths of the two s-wave survey lines (PPC 2002b). It was mutually agreed to conduct the s-wave survey on p-wave survey line L2 between stations 340 and 560 (i.e., 1100 linear ft) and on p-wave survey line L3 between stations 450 and 690 (i.e., 1200 linear ft) (PPC 2002b). These locations were selected based on anomalies identified in the p-wave survey results. These stations also included the calculated roll-on and roll-off lengths to obtain full subsurface coverage (full fold) where the anomalies began and ended on these lines.

2.2 SUMMARY OF WORK PERFORMED

The s-wave survey was performed by SAIC Engineering, Inc., and its subcontractor, Blackhawk GeoServices. SAIC is under subcontract to Bechtel Jacobs Company LLC (BJC), the DOE's Management and Integration contractor.

The s-wave survey was conducted along portions of p-wave survey lines L2 and L3, which were surveyed during the previous p-wave survey (SAIC 2002). The s-wave survey was conducted from January 30 through February 4, 2002. The survey was conducted using the Bay Geophysical MicroVibrator shear wave source, a 96-channel seismograph, and 40Hz horizontal component geophones. The geophones were placed at 2-ft intervals and "shots" (using the MicroVibrator energy source) were taken at 2-ft intervals. Figure D.2 illustrates the locations of both s-wave survey lines at Site 3A. Blackhawk GeoServices processed the data, and their report is contained in Attachment D-I of this technical memorandum. The Blackhawk GeoServices report contains detailed information regarding the data acquisition, data processing, and interpretation of results.

2.3 DEVIATIONS FROM PLANNED ACTIVITIES

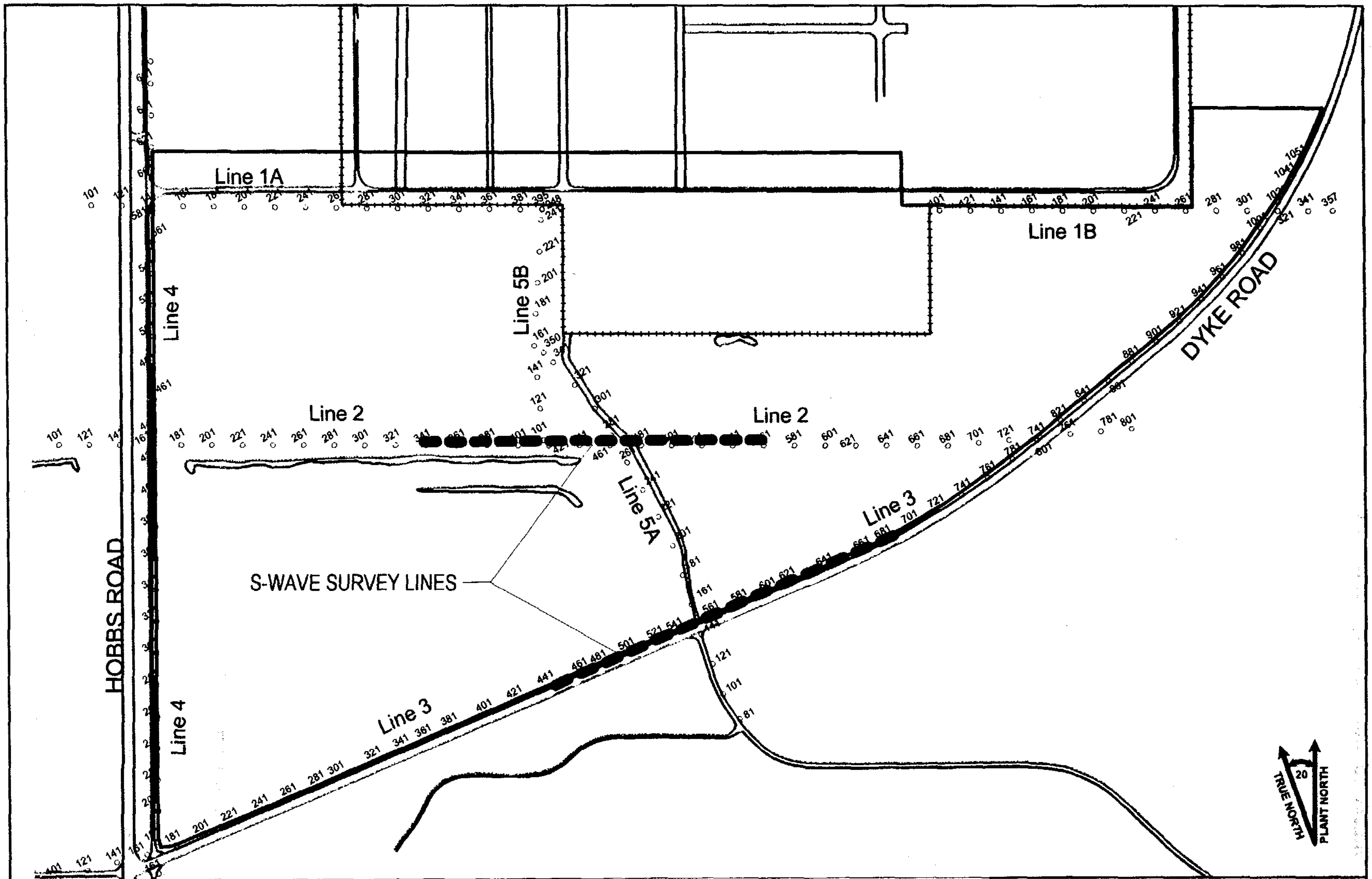
During the s-wave survey, there was one deviation from the Seismic Assessment Plan (BJC 2001). The plan called for three lines to be run totaling approximately 1500 ft. As previously described in Sect. 2.1 of this technical memorandum, DOE, EPA, and the Commonwealth of Kentucky agreed to conduct the s-wave survey at two locations, totaling approximately 2300 ft (PPC 2002b).

2.4 DATA ACQUIRED

The results of the s-wave survey are presented in Attachment D-I of this technical memorandum. The attachment consists of the *Shear-Wave Seismic Survey Report* prepared by Blackhawk GeoServices. It contains processed data from both survey lines (i.e., L2 and L3).

2.5 SUMMARY OF RESULTS

The resolution of the s-wave survey data was considered to be excellent for its intended purpose. Several shallow horizons were successfully imaged beneath Site 3A, including the loess, a firm sand unit underlying the loess, and the Porters Creek Clay. The s-wave survey results generally complemented the conclusions derived from the previous p-wave survey (SAIC 2002). The locations of some previously interpreted faults were refined, and in many cases, extended closer to the surface based on these results. Also, because of the higher resolution of the data, additional faulting was interpreted.



LEGEND

ROAD

PGDP BOUNDARY

BOUNDARY OF SITE 3A

S-WAVE SURVEY LINE

301 ○ P-WAVE SURVEY STATION

500 0 500 Feet

Fig. D.2. Location of s-wave survey lines.

U.S. DEPARTMENT OF ENERGY
DOE OAK RIDGE OPERATIONS
PADUCAH GASEOUS DIFFUSION PLANT

BECHTEL JACOBS
BECHTEL JACOBS COMPANY LLC
MANAGED FOR THE US DEPARTMENT OF ENERGY UNDER US GOVERNMENT CONTRACT DE-AC-05-98OR22700
Oak Ridge, Tennessee • Paducah, Kentucky • Portsmouth, Ohio

SAIC
Science Applications International Corporation
P.O. Box 2502
Oak Ridge, Tennessee 37831

FIGURE No. c5ac90001sk504r2.apr
DATE 07-10-02

3. GPR SURVEY

GPR is a nonintrusive electromagnetic geophysical survey method to detect anomalies in the shallow subsurface. A summary of this geophysical technique is presented in the Blackhawk GeoSciences GPR Calibration Study Report (SAIC 2002). As described in Sect. 3.1.3.2 of Part II of the Seismic Assessment Plan (BJC 2001), "The purpose of this GPR survey, like the s-wave survey, is to provide higher resolution data, which may better define potential faulting of the uppermost sediments, and to refine the locations of the planned intrusive activities." The results of the previous GPR calibration survey indicated, however, that the GPR technology is incapable of penetrating local clays and silts to identify subsurface features (SAIC 2002). As a result, DOE, EPA, and the Commonwealth of Kentucky mutually agreed that the GPR survey should not be conducted as one of the follow-up activities at Site 3A (PPC 2002a).

4. DPT SURVEY

DPT is an intrusive method for collecting continuous 4-ft long subsurface soil core samples. The DPT advances a small-diameter core barrel (approximately 2 in.) by means of a hydraulic ram and/or hydraulic hammer. Although somewhat depth-limited (approximately 50 ft at the PGDP), the DPT, when compared to conventional drilling methods, is fast, convenient, and generates minimal volumes of waste by-products.

The purpose of the DPT survey was to collect soil cores to potentially identify faulting and/or displacement of relatively shallow unconsolidated units. Ideally, the DPT cores would allow evaluation of stratigraphy and observation of disrupted bedding, and would contain organic samples that could be collected for carbon-14 (^{14}C) age dating.

4.1 PLANNED ACTIVITIES

The planned DPT survey activities are described in Sect. 3.1.3.3 of Part II of the Seismic Assessment Plan (BJC 2001a) as follows:

> The DPT will allow continuous samples to be collected from the surface to refusal (i.e., when the rig is unable to push the DPT further into the earth), which is anticipated to be approximately 30 ft... The DPT holes will be completed at two locations approximately perpendicular to and intersecting the hypothetical fault. Five DPT holes will be completed at each location, with one DPT hole located over the fault, and the remaining DPT holes located on each side of the potential fault. The DPT holes will be spaced approximately 50 ft apart... Up to four organic samples (total) may be collected from the DPTs and sent to an approved off-site laboratory for ^{14}C age dating.

During the January 15, 2001, meeting, DOE, EPA, and the Commonwealth of Kentucky agreed that the two lines of DPTs should be conducted along the same lines as the s-wave survey (PPC 2002a). (As previously indicated in Sect. 2.1 of this technical memorandum, it was mutually agreed to conduct the s-wave survey on p-wave survey line L2 between stations 340 and 560 and on p-wave survey line L3 between stations 450 and 690.) These locations were selected based on anomalies identified in the p-wave survey lines (SAIC 2002).

4.2 SUMMARY OF WORK PERFORMED

The DPT survey was performed by SAIC and its subcontractor, Gregg In Situ, Inc. SAIC is under subcontract to BJC, the DOE's Management and Integration contractor.

The DPT survey was conducted February 24 through March 8, 2002, with Gregg In Situ's 22-ton *RHINO* track rig. Four DPTs were driven along p-wave survey line L2, and six DPTs were driven along p-wave survey line L3 (SAIC 2002). Figure D.3 illustrates the locations of the DPT boreholes at Site 3A. All DPT cores were placed in wooden core boxes, logged by a geologist, photographed, and subsequently placed in storage. Table D.1 contains a summary of the DPT survey activities. As planned, the DPT boreholes were pushed to a depth of 30 ft or deeper, with two exceptions that reached refusal prior to reaching a depth of 30 ft (e.g., the DPT boreholes at Station 440 on p-wave survey line L2 and Station 531 on p-wave survey line L3). As shown in Table D.2, five organic samples were collected, and the laboratory was able to conduct ^{14}C age dating on four of the samples.

Table D.1. DPT summary

DPT location			PGDP coordinates [b]			
P-wave line	P-wave station	Elevation [a] (ft msl)	Northing (ft)	Easting (ft)	Total depth (ft)	Date conducted
Line L2	400	388.75	-6701.73	-3604.38	32.0	Feb. 26, 2002
Line L2	440	392.74	-6711.16	-3404.98	21.6[c]	Feb. 25, 2002
Line L2	500	393.39	-6739.18	-3104.51	32.0	Feb. 25, 2002
Line L2	523	393.22	-6745.75	-2986.55	32.0	Feb. 26, 2002
Line L3	490	400.65	-7386.59	-3297.26	42.0	Feb. 25, 2002
Line L3	520	398.86	-7328.19	-3157.98	42.0	Feb. 24, 2002
Line L3	531	398.16	-7307.01	-3103.44	28.8	Feb. 25, 2002
Line L3	590	396.11	-7192.17	-2837.22	42.0	Feb. 24, 2002
Line L3	620	395.01	-7134.77	-2697.95	42.0	Feb. 24, 2002
Line L3	670	392.56	-7036.34	-2475.31	40.0	Feb. 26–27, 2002
SB-04		382.28	-5971.77	-1377.72	40.0[c]	Mar. 8, 2002

[a]Basis for elevations is the U.S. Coastal and Geodetic Survey North American Vertical Datum of 1988.

[b]Basis for coordinates is the U.S. Coastal and Geodetic Survey North American Datum of 1983. Coordinates are presented using the PGDP coordinate system.

[c]Refusal depth

msl = mean sea level

Table D.2. Summary of organic sampling and ^{14}C age dating

Sample number	DPT location		Sample depth (ft)	Measured radiocarbon age[a] (years BP)	Conventional radiocarbon age[a] (years BP)
	P-wave line	P-wave station			
CCGTD400L2	Line L2	400	10.5	Insufficient carbon	Insufficient carbon
CCGTD440L2	Line L2	440	10	13,540 ± 60	13,570 ± 60
CCGTD500L2	Line L2	500	3.2	3,770 ± 50	3,790 ± 50
CCGTD620L3	Line L3	620	5.2	13,850 ± 60	13,900 ± 60
CCGTD670L3	Line L3	670	10.2	15,620 ± 70	15,670 ± 70

[a]Dates are reported as radiocarbon years before present (BP), where "present" is considered to be 1950 A.D.

4.3 DEVIATIONS FROM PLANNED ACTIVITIES

During the DPT Survey, there were three deviations from the Seismic Assessment Plan (BJC 2001).

First, the original plan called for five DPT boreholes to be completed at two locations (i.e., a total of ten DPT boreholes). The plan also called for the DPT boreholes to "be spaced approximately 50 ft apart." However, subsequent discussions with the EPA and Commonwealth of Kentucky confirmed that the

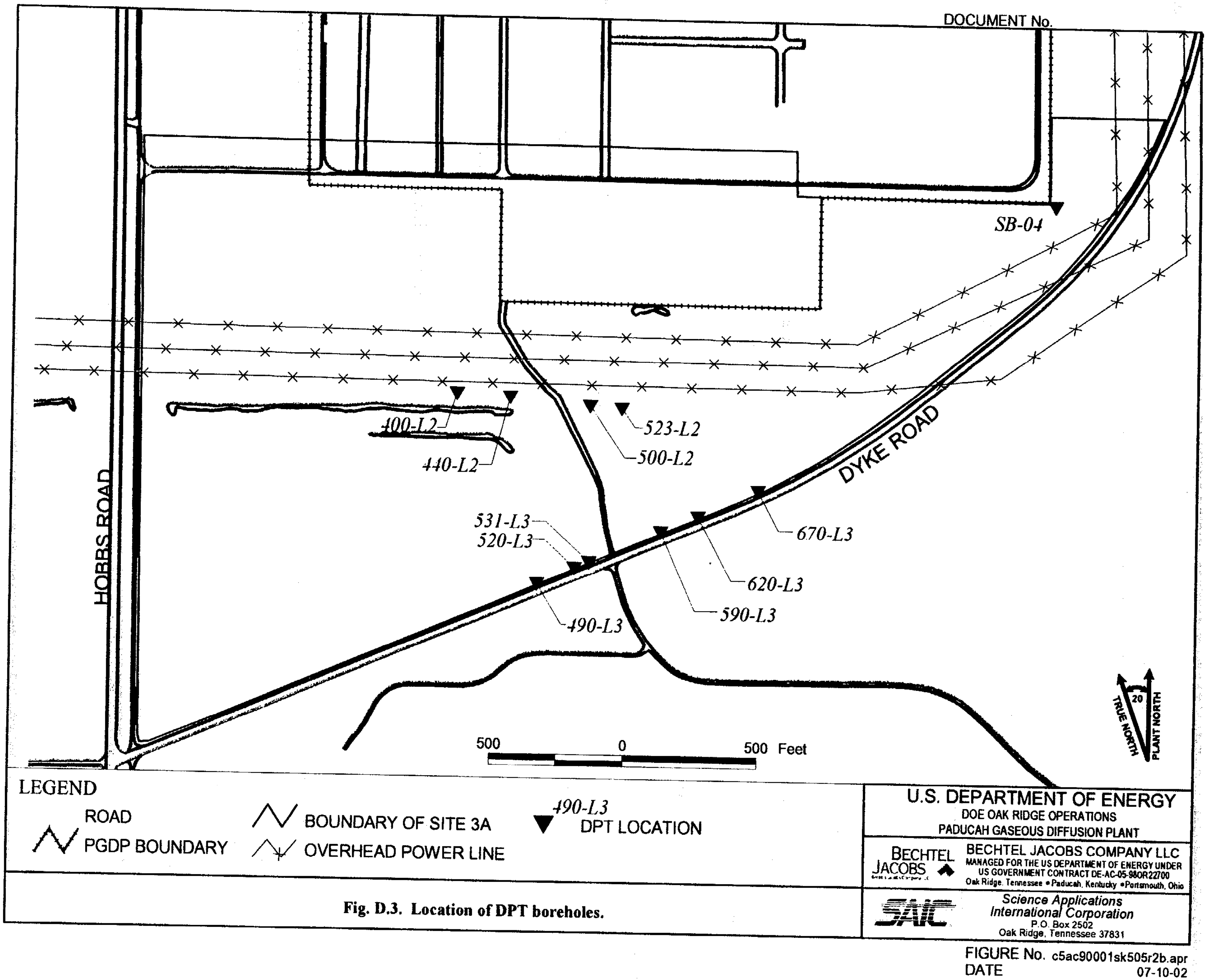


Fig. D.3. Location of DPT boreholes.

specific locations of the DPT boreholes should be based on the results of the s-wave survey and any other pertinent field data such as previously pushed DPT boreholes. The general locations of the DPT boreholes were discussed with EPA and the Commonwealth of Kentucky during the January 15, 2002, meeting (PPC 2002a). A total of 10 DPT boreholes were conducted at the two locations (i.e., near the s-wave survey locations on p-wave survey lines L2 and L3). Four of these DPT boreholes were located along p-wave survey line L2, and six of these DPT boreholes were located along p-wave survey line L3. This deviation enhanced the quality of the survey because the increased spacing of the DPT boreholes allowed a larger area with more features (e.g., subsurface anomalies) to be characterized.

Second, the plan called for collecting "up to four organic samples (total)" for ^{14}C age dating. As shown in Table D.2, five samples were collected, and the laboratory was able to conduct ^{14}C age dating on four of the samples. This deviation did not affect the quality of the DPT survey. (If the fifth sample could have been analyzed, it would have provided more data than initially planned.)

Third, the plan called for location CCGT-SB04 to be a shallow boring. Heavy rainfall created accessibility concerns for the truck-mounted rigs that were used to drill the shallow borings. Because the DPT rig was mounted on a tracked vehicle, the DOE investigation team decided to replace the planned shallow boring with a DPT boring. Additionally, this location is not in the footprint of the potential disposal cell but is located in the footprint of the associated support facilities. This modification to the plan was provided to EPA and the Commonwealth of Kentucky (PPC 2002c and 2002d). This deviation did not affect the quality of the DPT survey, because it allowed an additional DPT core to be collected.

4.4 DATA ACQUIRED

The results of DPT survey are presented in Attachments D-II and D-III of this technical memorandum. Attachment D-II contains the drilling logs and Attachment D-III contains the laboratory results of the ^{14}C age dating analyses.

4.5 SUMMARY OF RESULTS

The DPT survey achieved its intended objective. Eleven DPT boreholes were pushed, and a total of 392.4 ft of core was collected. The soil cores that were collected allowed the stratigraphy to be observed and organic samples to be collected for ^{14}C age dating. A fault was observed at a depth of 28 ft in the DPT core from Line 3, Station 531. (The location of this DPT borehole was chosen based on the s-wave survey results.) Five organic samples were collected, and the laboratory was able to analyze four of the samples.

5. TEST PITS AND TRENCHING

As described in Sect. 3.1.3.4 of Part II of the Seismic Assessment Plan (BJC 2001), three test pits were planned to be excavated to a maximum depth of 15 ft at a suspected fault location to acquire visual evidence of any near-surface fault displacement. As described in Sect. 3.1.3.5 of Part II of the Seismic Assessment Plan (BJC 2001), one trench was planned to be excavated to a maximum depth of 10 ft perpendicular to a suspected fault location to acquire visual evidence of any near-surface fault displacement. The trench was to be constructed to allow personnel to enter and collect organic samples for ^{14}C age dating.

Based on the results of the DPT survey and the site-specific Geotechnical Study, the DOE investigation team determined that the test pits and trench should not be constructed. This decision also was based on field conditions that would prohibit these activities as planned (e.g., high water levels, excessive excavation required to reach required depths, and obstructions, including trees/woods, paved roads, an underground utility, and potential wetlands). These conditions presented safety and environmental impact issues that were not anticipated in the planning phase of the project. This decision was conveyed to the EPA and Commonwealth of Kentucky (PPC 2002c, 2002d, 2002e, and 2002f).

6. REFERENCES

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ATTACHMENT D-I

S-WAVE SURVEY RESULTS

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BLACKHAWK
GeoServices
Southeast Region

DRAFT

DRAFT
SHEAR-WAVE SEISMIC SURVEY REPORT

Site 3A Seismic Assessment
Paducah Gaseous Diffusion Plant

Paducah, Kentucky

Blackhawk GeoServices Project No. 2901SAI

Prepared for

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EXECUTIVE SUMMARY

Representatives and support staffs of the U.S. Department of Energy, the U.S. Environmental Protection Agency, and the Commonwealth of Kentucky, have developed a field investigation program to address seismic issues associated with potentially siting a CERCLA waste disposal facility at the Paducah Gaseous Diffusion Plant. The results of these investigations will be used as input to the feasibility study of disposal options for CERCLA-derived waste.

One of the potential disposal facility sites presently under consideration is Site 3A. This site is located on DOE property, south of the present security fence. As part of the planned field program, approximately 16,000 linear feet of p-wave seismic reflection data were collected in November 2001 to identify potential subsurface anomalies that may indicate the presence of faults. The target zone for the p-wave survey extended from the bedrock surface (located at a depth of approximately 390 feet below ground surface) upward into the overlying McNairy and Porters Creek Clay Formations. The second portion of the planned seismic field program was the acquisition of 2,300 linear feet of horizontal s-wave reflection data targeting the very shallow sediments located immediately above select faults interpreted from the p-wave study. The s-wave portion of the seismic field program was completed in February 2002.

The s-wave seismic reflection survey was successful in imaging several near-surface horizons and faults beneath Site 3A. Horizons evident in the s-wave data include the near-surface loess, a firm sand unit underlying the loess, and the Porters Creek Clay. A total of 5 faults were investigated during the s-wave study, and overall, these profiles support the general conclusions derived from the earlier p-wave study.

For most of the faults in this area, relative movement along the main fault plane is normal, with the downthrown side to the east. These normal faults, along with their associated splays, either form a series of narrow horst and graben features, or divide the local sediments into a series of rotated blocks.

The overall trend and geometry of the faulting is consistent with extensional regional tectonics and faulting observed in the Fluorspar Area Fault Complex of Massac County, Illinois, located just across the Ohio River.

Most of the faults identified in the p-wave data for further characterization using shear waves have been confirmed to extend upward into younger sediments overlying limestone bedrock, three of which are interpreted to extend to within approximately 20 feet of the surface.

Young faulting is evident on the shear wave sections, and the profiles provide target areas for further intrusive investigations.

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) is the lead agency at the Paducah Gaseous Diffusion Plant (PGDP). The general location of PGDP is presented in **Figure 1**. The U.S. Environmental Protection Agency (EPA) and the Commonwealth of Kentucky pursuant to the Federal Facility Agreement (FFA) regulate environmental restoration activities at PGDP.

Over the past year, representatives from EPA, the Commonwealth of Kentucky, and DOE and their support staffs have developed a field investigation program to address seismic issues associated with potentially siting a CERCLA waste disposal facility at the PGDP (BJC 2001). The results of these investigations will be used as input to the feasibility study of disposal options for CERCLA-derived waste at PGDP. One of the potential disposal facility sites presently under consideration is referred to as Site 3A. This site is located on DOE property, south of the present security fence **(Figure 2)**.

As the second part of this field investigation program, Blackhawk GeoServices (BHG), in partnership with our subsidiary, Bay Geophysical, performed a horizontal shear-wave (s-wave) seismic reflection survey at Site 3A from January 30 to February 4, 2002. This phase of seismic work was located over areas of interest highlighted by the initial compressional wave (p-wave) seismic investigation performed in November and December of 2001. The work was performed under subcontract number 4400047316 with Science Applications International Corporation (SAIC).

For this study, s-wave seismic reflection data were acquired along two survey lines (Lines 2S and 3S) totaling approximately 2,300 linear feet of surface coverage. The locations of the survey lines relative to PGDP, permanent geographic features, and the previous p-wave seismic profiles are shown in **Figure 2**. A detailed view of Lines 2S and 3S relative to p-wave survey Lines 2 and 3 is presented as **Figure 3**. For production work, key seismic equipment used to collect the data included:

- Bay Geophysical MicroVibrator,
- 96-channel OYO DAS-1 Seismograph,
- 40-Hz OYO SMC70 horizontal component geophones.

This report summarizes all data acquisition and field methods used to conduct the investigation, and includes sections on data processing, interpretation, conclusions and recommendations.

1.1 PROJECT OBJECTIVES

The purpose of the Site 3A s-wave seismic reflection survey is to further resolve the near surface expression of anomalies interpreted to be faults that were identified in the initial p-wave survey data. Specifically, the target zone of the s-wave study extends from as near to the ground surface as possible to an approximate depth of 50 feet below ground surface (bgs), or roughly to the top of the Porters Creek Clay Formation.

The first phase of seismic reflection work was designed to image faulting within a target zone lying between the bedrock surface (approximately 390 feet bgs) and the overlying McNairy and Porters Creek Clay Formations. These initial reflection profiles reveal the presence of normal faults within the area of investigation, generally trending north-northeast (NNE). Eleven faults are interpreted to show disruptions near the top of the bedrock limestone that appear to offset that unit. Nine of the eleven faults are interpreted to extend upward into younger sediments above limestone bedrock. Relative movement along the fault blocks throughout Site 3A appears to be complex, with generally horst and graben structures in the eastern portion of the survey area, and blocks that have rotated (or dip) toward the west in the western portion of site.

Based on the p-wave seismic results, the area of investigation for the s-wave study was narrowed to focus on those interpreted faults that 1) appear to extend upward into young sediments overlying bedrock, 2) are adjacent to or encompass the significant anticline-type structural feature, and 3) trend through the central portion of Site 3A.

1.2 GEOLOGIC SETTING

Site geology is thought to consist of varying thickness sand, silt, and clay units from the surface to an estimated depth of 390 feet bgs, where limestone bedrock occurs. Quaternary aged loess and fine-grained continental deposits overlie gravel deposits at a depth of approximately 20 feet bgs. Key near-surface reflection horizons at Site 3A include the loess, a firm sand unit underlying the gravel deposits, and the Paleocene-age Porters Creek Clay Formation. Units that lie below the depth of investigation for this survey include the Cretaceous-age McNairy Formation and the limestone bedrock. At Site 3A, the 55 to 60 million year-old Porters Creek Clay Formation occurs at a depth of approximately 50 to 60 feet bgs and is underlain by the McNairy Formation at a depth of approximately 160 to 180 feet bgs. The Porters Creek is generally a firm clayey/silty formation. The McNairy is generally a sandy formation, interbedded with varying thickness silt and clay units. Mississippian-age limestone bedrock underlies the McNairy Formation.

The bedrock, McNairy, and Porters Creek Clay units are thought to be laterally continuous across Site 3A and to possess a reasonably high acoustic contrast relative to adjacent units, such that seismic reflections likely will be seen in the data. The initial p-wave seismic reflection survey focused on identifying faulting at the top of bedrock and the top of the McNairy Formation. The s-wave survey focused on identifying faulting between the surface and the top of the Porters Creek Clay unit. Based on the regional geologic setting and mapping in the Fluorspar Area Fault Complex of Massac County, Illinois located just across the Ohio River from Paducah, Kentucky, if faulting is present at the PGDP, it would be expected to trend northeast and consist mostly of high-angle normal faults that outline horsts and grabens (Nelson 1998).

2.0 DATA ACQUISITION

This section describes the seismic methods and field procedures used to conduct the Site 3A investigation including survey control, source testing, and production parameters.

2.1 GENERAL

Seismic Reflection Technique

Seismic reflection profiling is a standard technique employed by the oil and gas exploration industry. The use of this technique in shallow engineering and environmental projects has been a relatively recent phenomenon, as the formerly high production costs and serious computing requirements were prohibitive. Advances in microelectronics have led to engineering seismographs and PC-based processing that now permit the cost-effective use of reflection seismic methods in a wide variety of applications (Steeples and Miller 1988).

Details of the general seismic reflection technique can be found in many comprehensive texts, such as Sheriff and Geldart (1995); therefore, only a brief synopsis of the basic principles is presented here, with particular emphasis on the characteristics of shear waves.

The seismic reflection technique can be divided into two categories based on the type of seismic energy used. Compressional, or p-waves, propagate through the earth as a series of compressions and rarifications, and are identical to ordinary sound waves. As shown in the upper portion of **Figure 4**, particle motion for p-waves is parallel with the direction of propagation. Shear waves, or s-waves, propagate through the earth by distorting the shape of the medium they are passing through. The middle portion of **Figure 4** shows particle motion in s-waves is perpendicular to the direction of wave propagation. An important feature of shear waves is that, unlike p-waves, they will not propagate through liquids or gases, as these materials have no shear strength. This makes them particularly valuable for the detection of voids, fractures, and faults.

Civil engineers have been using shear wave velocities since the 1940's to determine elastic moduli of near surface materials, which are linked to material properties of rock and thus to the safety of construction works such as dams or tunnels (Garotta 1999). Geophysicists, on the other hand, have moved cautiously to the use of shear waves. The oil and gas (O&G) industry experimented with shear wave techniques in the 1970's and 80's, but has for the most part discontinued their use except for special applications. This was primarily because p-waves did a better job for targets on the order of several thousand feet below ground surface. Shear wave propagation through the earth is generally limited to a few hundred times their wavelength before attenuating below detectable levels (Helbig 1987). For the O&G industry, this is a serious limitation.

The application of shear wave reflection techniques to shallow subsurface investigations began in the 1990's. For these applications, the limitations imposed by the attenuation of shear waves over distance are no longer applicable. On the contrary, for engineering and environmental applications, s-waves provide higher resolution and resolve shallower targets than p-waves. This is mostly because s-wave velocities are slower than p-wave velocities, resulting in greater subsurface resolution, and s-waves are generally not affected by shallow groundwater tables, which results in greater resolution, particularly in low velocity unconsolidated sediments like those at PGDP.

Seismic Reflection

The basic principles of the reflection technique are illustrated in **Figure 5**. The seismic reflection method involves projecting acoustic energy down from the surface, and then recording the acoustic energy back at the surface as it reflects off of formations at depth. Seismic energy is also refracted and diffracted at boundaries in the subsurface, in accordance with Snell's Law. One of the main design considerations for a successful seismic reflection survey is the ability to separate the reflected energy from the other arrivals in processing.

A seismic reflection occurs when an acoustic wavefront encounters an impedance boundary in the subsurface. Seismic impedance depends on both the velocity and density of a rock, and impedance boundaries occur where these rock properties change abruptly, usually due to changes in lithology. The reflection coefficient, R, across an interface, is expressed by a function relating the acoustic impedance of adjacent layers. R determines the relative amplitude of the reflected wavelet.

$$\mathbf{R} = \frac{\sigma_2 \mathbf{V}_2 - \sigma_1 \mathbf{V}_1}{\sigma_2 \mathbf{V}_2 + \sigma_1 \mathbf{V}_1}$$

where, R = reflection coefficient,
σ_1, σ_2 = mass density of the material on each side of the interface, and
V_1, V_2 = p-wave velocity on each side of the interface.

The sign of the reflection coefficient determines the polarity of the reflected wave. The magnitude of the reflection coefficient is critical to obtaining usable data. The seismic reflection technique will not work if the acoustic contrast is not sufficient to produce a clear reflection, regardless of the survey parameters or processing techniques employed. The ability of the seismic reflection method to detect an individual sedimentary bed is not only a function of the acoustic impedance at the top and bottom of the bed, but also depends on the layer thickness. The minimum resolvable bed thickness is often quoted as 1/4 to 1/8 of the wavelength of the seismic reflection. Wavelength is inversely proportional to frequency.

That is:

$$\nu = f\lambda$$

where, ν = acoustic propagation velocity,
f = frequency, and
λ = wavelength.

Wavelength controls vertical resolution, and is obviously dependent on frequency and velocity, with shorter wavelengths resolving smaller subsurface features than longer wavelengths. Generally, shear waves travel at roughly half the velocity of p-waves; therefore, for a given frequency, shear waves will have approximately half the wavelength, translating to twice the resolution.

Shear wave velocities in the Site 3A area have been determined by previous downhole surveys performed at PGDP. **Figure 6A** presents stratigraphy and corresponding s-wave velocities acquired from a nearby borehole north of Site 3A. **Figure 6B** presents s-wave and p-wave velocity data from borehole DB02 that were recently acquired with a P-S Suspension logger along p-wave seismic Line

5A. From **Figure 6B**, it's evident that s-wave velocities above the water table (~20 feet bgs) are roughly half the velocity of p-waves, whereas below the water table, p-wave velocities increase significantly to the approximate velocity for water [~5,000 feet per second (ft/s)] and the s-wave velocities generally remain unchanged. Below the water, this translates to an s-wave velocity that is roughly 4 times slower than the p-wave velocity.

At Site 3A, shear wave interval velocities in the sedimentary layers above bedrock are less than 2,000 feet per second. The frequencies put into the ground by the MicroVibrator ranged from 40-300 Hertz (Hz) and recoverable frequencies ranged from 40-280 Hz. **Table 2-1** compares the frequencies, velocities and wavelengths for the site area, with consideration to the data acquisition parameters used and recovered signal frequencies.

TABLE 2-1

VELOCITY, FREQUENCY, AND WAVELENGTH RELATIONSHIPS FOR RESOLUTION OF POST-PALEOZOIC FAULTS

Velocity ft/s	Frequency Hz	Wavelength ft	Vertical Offset Mapping Limit ($1/4\ \lambda$), ft	Vertical Offset Detection Limit ($1/8\ \lambda$), ft
1,000	40	25.0	6.3	3.1
1,000	80	12.5	3.1	1.6
1,000	120	8.3	2.1	1.1
1,000	180	5.6	1.4	0.7
1,000	240	4.2	1.0	0.5
2,000	40	50.0	12.5	6.3
2,000	80	25.0	6.3	3.1
2,000	120	16.6	4.2	2.1
2,000	180	11.1	2.8	1.4
2,000	240	8.3	2.1	1.0
3,000	40	75.0	18.8	9.4
3,000	80	37.5	9.4	4.7
3,000	120	25.0	6.3	3.1
3,000	180	16.7	4.2	2.1
3,000	240	12.5	3.1	1.6

When a reflecting boundary exists, it's important to optimize the field procedure and acquisition parameters to ensure the quality of the final processed data. Choosing the best field parameters involves determining the relative importance of several competing objectives, such as site constraints, equipment capabilities, and processing needs.

In all geophysical surveys, the objective is to extract the usable data (i.e., in this case, reflections from various lithologic boundaries) from the unwanted background information (geologic and ambient noise). In reflection seismology, it's desirable to record high frequency, high signal-to-noise ratio reflection events from the boundary of interest. The frequency of a reflection event is largely determined by the source input frequency and the filtering effect of the ground. Often, the target reflector frequency is similar to that commonly recorded for coherent noise (in particular, the noise from ground roll), making it difficult or impossible to selectively filter out the noise. Isolation of the reflection events requires careful design of field acquisition parameters, such as the source/receiver geometry, choice of source and receiver types, as well as recording parameters, such as sampling rate and filter settings. The choice of these parameters is discussed in Section 2.2.

In general, s-wave data is more difficult to assess in the field than p-wave data. The primary reason for this is the predominance of Love waves on the shot records, which are usually strong enough to mask all other arrivals below first breaks. Love waves are surface waves involving transverse motion parallel to the surface of the ground, and have velocities intermediate between the s-wave velocity at the surface and the s-wave velocity in deeper layers **(Figure 7)**. Because these waves are trapped in the near surface layer or weathering layer, they attenuate slower than other seismic waves, and are often the strongest events on the record. Love waves are not seen on p-wave data, and are unique to the shear wave reflection method.

Figure 8 presents a raw s-wave production shot from Line 3 (Shotpoint 549.5). The seismic source is located between channels 48 and 49. The first breaks on this record are direct arrivals near the source, and become refractions at the longer offsets. Beneath the first breaks, high amplitude Love waves can be seen propagating throughout the record. Fortunately, this coherent, source-generated noise can be mitigated with a number of field and processing tools. In the field, the application of a 100 Hz Low-Cut filter revealed the underlying reflectors. During data processing, velocity filtering or statistical noise attenuation algorithms were applied to the data to remove this unwanted signal.

Figure 9 presents the same shot record from Line 3, after Love wave mitigation. This record demonstrates the relationships between the s-wave reflection and refraction events within the zone from 60-120 milliseconds (msec) and several s-wave reflectors that were previously obscured by Love waves. Note that ground roll (Rayleigh waves) and the airwave are absent, since Rayleigh waves are surface waves that travel in the vertical plane and s-waves will not propagate through gases, respectively. The refraction event, highlighted in blue, is always the first to arrive at the long offset geophones and usually makes up the bulk of the first breaks. Refractions are characterized by linear moveout across the shot records, that is, they appear as straight segments. The reflection events, which dominate the areas highlighted in green, are characterized by a hyperbolic moveout. Multiple reflections, though not clearly evident in this shot record, result from a double bounce of acoustic energy between say, the surface and a hard layer **(Figure 10)**. Multiples display nearly the same hyperbolic moveout as primary reflections, and are typically easy to recognize. Some multiples <u>do</u> stack in on the final sections, and any interpreters working with these data need to be aware of their presence.

2.2 DESIGN OF SURVEY PARAMETERS

A summary of the production data acquisition parameters is provided in Section 2.5 and **Table 2-2**. For this phase of the project, the receiver group interval was 2 feet, with one 40-Hz horizontal component geophone located at each station. Shot records contain 96 live channels in a symmetric split spread configuration, except at the beginning and end of each line, where the MicroVibrator was rolling on and off of the spread. Data were recorded with a 0.5-msec sample rate and a record length after correlation of 1 second. The source parameters were determined by on-site testing.

2.2.1 Source Testing

During the first phase of the Site 3A Seismic Assessment, four seismic energy sources were tested along the northern portion of Line 4. Among these, the Bay MicroVibrator was used to acquire enough shots to process a short shear wave reflection profile. At that time, the objective was to image anomalies associated with faulting at depths near the level of bedrock limestone. For the initial test, the source interval was 10 feet and the receiver interval was 5 feet. The MicroVibrator source parameters, derived from field testing, were four 6-second sweeps over a frequency range of 20-200 Hz. This initial test laid the groundwork for the second phase of high-resolution shear wave surveys described in this report.

For the current phase of seismic work at Site 3A, the objective was to focus on the interval from as near to the ground surface as possible to an approximate depth of 50 feet bgs, or roughly to the top of the Porters Creek Clay Formation. The higher resolution requirements of these profiles required a reduction in source and geophone interval (down to 2 feet) and a re-evaluation of the sweep parameters.

The MicroVibrator used on this project is patented to Bay Geophysical, and shown along Line 3S in **Figure 11**. The MicroVibrator has a hold down weight of approximately 300 pounds, and is coupled to the ground by several large spikes (or smaller spikes as conditions warrant). It generates a sweep by oscillating a mass through a user-defined range of frequencies, which are transmitted into the ground.

Typically, the advantages of using a vibratory source for reflection work include a higher signal-to-noise ratio when compared to impulsive sources, such as the hammer and cylinder, weight-drops, or dynamite. This is due to the statistics of the correlation process and the ability to control the frequencies put into the ground. Another advantage is that particle motion amplitudes are much lower with vibratory sources, greatly reducing or eliminating damage to any nearby surface structures. This is because the energy of a vibratory source is input into the ground over a relatively long time interval.

Vibratory sources function by holding a plate on the ground and vibrating the plate through a user-defined range of frequencies, known as a "sweep." The length of the sweep, peak force, and frequency range can be changed in the field. At the instant the vibrator begins its sweep, the seismograph begins recording the signals received from the geophones. The seismic signal created by the sweep is received by the geophones and stored in the seismograph. By correlating the recorded signals from the geophones with the known sweep generated by the vibrator, a seismic trace is obtained.

Frequency Content

For vibratory sources, the frequency content of seismic reflection data is initially a function of the beginning and ending frequencies of the sweep, the length of the sweep, and the ground coupling. A primary factor affecting data quality is the transmission and attenuation of various frequency components in the subsurface, often termed the "earth response."

In general, there are two primary objectives in designing a sweep for high-resolution reflection surveys:

- To record useful seismic signals at the geophones with as high a frequency as possible; and
- To start the low end of the sweep such that the appropriate depth of penetration is achieved without generating intolerable amount of source noise.

With the start of fieldwork on January 30, 2002, source parameter testing was carried out on the west end of Line 3S. The receiver interval and geophone array had been determined before the start of the survey. Sweeps of varying frequency bandwidths were recorded into a full (96 trace) split spread configuration in an effort to bracket the usable frequencies returning to the geophones from the subsurface. The initial testing, aided by frequency filtering in the recording instruments, determined that the best source parameters for the current phase of work were four 8-second sweeps over a frequency range of 40-300 Hz.

2.3 SITE-SPECIFIC PROBLEMS

In addition to the general requirements for seismic data acquisition described in Section 2.1, two site-specific problems were known to exist or became apparent during the Site 3A s-wave survey.

Wet and/or Muddy Areas

Wet and/or muddy areas were encountered along Line 2S. During the initial p-wave surveys, the east end of Line 2 was particularly wet and muddy, and this was manifested in a noticeable deterioration in data quality along that portion of the line (the seismic field crew had to resort to hammer and cylinder techniques in this area). For this phase of seismic data acquisition, steps were taken to mitigate the surface problems along Line 2. First, the s-wave Line 2S was shifted an average of 10 feet to the north to place the seismic line on slightly higher ground. Secondly, since the new line location placed the seismic stations along a fairly steep fill slope from station 670 to the east end of the line **(Figure 3)**, a bulldozer was used to carve a notch such that the MicroVibrator could be deployed in a relatively level position. Both steps were well worth the effort. Data quality along the east half of Line 2S is excellent.

Due to recent heavy rains, the west half of Line 2S remained in a wet/swampy condition at the time of the survey. Relocating the line 10 feet north improved the situation somewhat in this area as well. However, a deterioration in data quality was noticed on the shot records as the MicroVibrator progressed into the soft ground. To improve source coupling in this area, the number of sweeps was increased from four to eight per shotpoint. In addition, two field crew members stood on the MicroVibrator during data acquisition, which increased the hold-down weight and forced the MicroVibrator to couple more firmly in the soft ground. These steps probably improved data quality on this end of the line, although there remains a significant change of character (less reflectors) on the west half of Line 2S.

Line 3S was shot along the elevated shoulder of Dyke Road, and there were no problems related to soft ground on this line.

Overhead Power Lines

Power lines often cause 60 and 120 Hz noise on some receiver channels due to induction from the surrounding electromagnetic field into the geophone elements. Power line noise problems are most severe when the ground is damp. Line 2S paralleled an overhead power line corridor, although only minor effects were evident in the data. For field QC purposes, a notch filter was applied to the shot records (display only), effectively removing 60 Hz noise so that reflectors could be more easily monitored. In data processing, the most effective tool for removing induced noise is the stacking process.

2.4 HEALTH AND SAFETY (H&S)

The Site 3A seismic survey was conducted under the Health and Safety Plan prepared by SAIC. SAIC personnel provided health and safety coverage. The survey was completed safely.

2.5 PRODUCTION PARAMETERS AND LINE INFORMATION

The nominal spread configuration is graphically represented in **Figure 12**. Production parameters for the seven Site 3A seismic lines are summarized in **Table 2-2**.

TABLE 2-2

NOMINAL SEISMIC REFLECTION ACQUISITION PARAMETERS

Shot Spacing	2 feet
Geophone Group Interval	2 feet
Nominal CDP Fold	48
Maximum Offset	95 feet
Minimum Offset	1 feet
Spread Geometry	Symmetric Split Spread 48/48 – (190 foot total active array)
Seismograph	2 OYO DAS-1 Recorders (Master/Slave)
Number of Channels	96
Sample Rate	0.5 ms
Record Length	1.0 second
Field Filters	3/18 – Out Hz/dB
Seismic Source	Bay MicroVibrator, - 300 lbs of peak ground force 40 to 300 Hz, Linear, 8 second sweep, 4 sweep/station
Geophones	1 X 40 OYO SMC70 40 Hz Shear Wave phone
Cables	48 pair cables with Amphib Heads, 4' takeouts, 24 takeouts / cable
Rollbox	I/O Inc. RLS-240M

Table 2-3 lists the lines surveyed and their number of stations. The lines are also shown on the seismic line location maps **(Figures 2 and 3)**.

TABLE 2-3

SUMMARY OF LINE AND STATION NUMBERS

Line Name	First Station	Last Station	# of Stations	Line Feet
2S	340	890	550	1,100
3S	450	1050	600	1,200

2.6 PRODUCTION PROCEDURES

A Kentucky-licensed surveyor surveyed the initial Phase 1 p-wave lines under the supervision of SAIC. At that time, stations were staked and XYZ coordinates shot on 100-foot centers. The stakes marking the original survey points were still in place when the s-wave survey began, and were therefore utilized to locate the new lines. Blackhawk personnel chained out stations on 2-foot centers and provided supplemental elevation shots, where necessary at high and low surface areas along each survey line. Line 2S was shifted an average of 10 feet to the north from the original p-wave survey stakes to avoid areas of standing water. Blackhawk personnel surveyed elevations along Line 2S and adjusted X,Y coordinates, as necessary, to reflect the actual location of the survey line. The elevation shots and coordinate adjustments were tied to existing Line 2 survey control. All XYZ coordinates were used by the seismic data processor to position the data, and perform statics analysis and datum corrections.

At the start of each line, the source was positioned at the first receiver station. Approximately 200 strings of geophones and 12 cables were mobilized to the field, allowing the crew to lay out the receiver spread well in advance of the recording. A total of 9 cables (216 channels) were connected to the OYO DAS-1 seismographs via the roll box at each recording vehicle set-up. The roll box selects the active geophones for each shot. A trigger cable connected the MicroVibrator to the seismographs, so when the operator pushed the trigger button in the recording truck, the vibrator began its sweep sequence and the seismographs began recording simultaneously. The synthetic sweep, output by a function generator in the recording truck, was recorded on auxiliary channel 2 in the master seismograph for correlation with the recorded data from the geophones. The uncorrelated data was written to the hard drive and to 4mm data tape. Correlated records were generated and written to tape after the completion of a line.

Typical field operations were as follows:

At the beginning of each day/line:

- An uncorrelated sweep was viewed either on the computer screen or on hardcopy. This provided a check to ensure that the vibrator was operating properly.
- Check array parameters (i.e., source location, sweep configuration, receiver spacing, etc.) and connections.
- Check the noise monitor on the seismographs to identify any ambient noise problems and to isolate and correct any noisy or dead receiver channels. The noise monitor was also useful for confirming the correct setting on the roll box by lightly tapping the first and last active phone.

Line production included:

- Starting each line with the source located at the first geophone station on the line, (the first shot would have 96 channels live in front of the MicroVibrator);
- Keeping the roll box in the initial position, the vibrator would "roll" into the spread, until there were 48 live channels on both sides;
- With a split spread, the roll box would be incremented by one on each shot, keeping the vibrator at the center of the active spread until reaching the last live channel; and
- Once the last live channel was reached, the vibrator would "roll" off the spread, in the reverse process to the start of the line. On the last shot, the Minivib would be at the last station, resulting in 96 live channels behind the MicroVibrator on the last shot.

After each cable at the beginning (low side) of the spread became inactive, the cable and geophones were advanced to the next cable position by the line crew (i.e., phones and cables occupying stations 1-24 would be moved to stations 217-264).

Effects of surface topography and variations in the upper layers of the earth are applied to the data (datum and automatic statics). Nonlinear effects of the data acquisition geometry (velocity analysis and normal moveout correction) are accounted for and removed in order to correctly image subsurface features. Directional filters are applied to the source (shot) records to eliminate unwanted signals generated by the seismic sources (surface wave / linear noise attenuation). Statistical data sets are sorted and then summed by subsurface reflection point (common midpoint stack). The data are spectrally whitened to adjust amplitudes of all frequency components and filtered to keep those reflection frequencies with the best signal/noise ratio (spectral balance).

Good sources for explaining seismic data processing can be found in Seismic Exploration Fundamentals by Coffeen, 1978, and Seismic Data Processing by Yilmaz, 1997.

4.0 INTERPRETATION

Site 3A interpreted seismic sections are presented as **Figures 13-16** and Site 3A fault interpretation maps are presented as **Figures 17-18**. In addition to the geophysical interpretation, the fault interpretation maps contain detailed information on reference features (e.g., roads, utility corridors, and fences), so that the survey lines and seismic anomaly locations can be relocated in the future. Uninterpreted s-wave seismic sections for Lines 2S and 3S are presented in **Appendix A**.

Figures 13-14 are interpreted Line 2 and Line 3 p-wave sections from the initial phase of reflection surveys completed in 2001. These sections display only those portions of the original Lines 2 and 3 where s-wave seismic data were also collected. These p-wave sections are presented using a conventional Wiggle Trace/ Variable Area (WT/VA) format. The red horizon is interpreted as the top of the McNairy Formation, and the yellow horizon is interpreted as the top of limestone bedrock. The p-wave surveys were designed to investigate faulting at the McNairy and Limestone levels, and the interpreted faults from the previous study are transposed onto these sections.

Figures 15-16 are the corresponding interpreted s-wave sections (Lines 2S and 3S). These sections are displayed with a horizontal scale equivalent to the p-wave sections. Since the s-wave data contains 2.5 times more traces than the p-wave data over the same line length, the conventional WT/VA format resulted in unaesthetic displays; therefore these sections are presented using a color-enhanced Variable Density format. In Variable Density format, blue reflectors correspond to amplitude peaks, and red reflectors correspond to amplitude troughs. Also note that on the shear wave sections, the top of data occurs at roughly 70 msec. This is a result of processing the s-wave data to the same datum as the p-wave data (500 feet). The slower correction velocity used to correct to datum (3,000 ft/s) manifests itself as a time lag on the shear wave profiles.

Figures 17-18 represent Fault Interpretation Maps from the initial p-wave and the current s-wave surveys, respectively. The locations of interpreted faults on the p-wave map **(Figure 17)** are based on the anomaly locations at the level of limestone bedrock (since that was the primary target zone for the investigation). The target zone for the s-wave survey is the upper 50 feet of subsurface, or roughly at a depth equal to the top of the Porters Creek Clay unit, hence the fault locations shown in **Figure 18** are based on the anomaly locations at the level of the Porters Creek Clay unit. Since most of the interpreted faults are thought to be steeply dipping, there is not much change in their positions on the two maps.

4.1 GENERAL CHARACTERISTICS

The s-wave surveys were designed to provide detailed information on the upper 50 feet of subsurface, or roughly to the top of the Porters Creek Clay Formation. The objective has clearly been met, as the data quality of the shear wave profiles is excellent (with the exception of the west end of Line 2S, where data quality was diminished somewhat due to swampy surface conditions). The initial interpretation step is to identify the primary reflecting horizons on the s-wave sections.

Hints of reflections caused by the top of the McNairy Formation and top of limestone bedrock are present in the shear wave data. However, since the survey was designed to focus on the upper 50 feet of subsurface, the reflections are weak and particularly for the limestone unit, probably not correctly represented in time. The former is due to the smaller seismic source used and higher frequencies employed, and the latter is primarily due to a lack of sufficient move-out to correctly determine a stacking velocity. For these reasons and to emphasize details in the target zone of this investigation, the shear wave sections have been truncated at 400 msec (~180 feet bgs), and have not been interpreted.

Interpreted Faults 4 through 8 from the initial p-wave seismic were confirmed following analysis of the s-wave data. For most of the faults in this area, relative movement along the main fault plane is normal, with the downthrown side to the east. Sediments within interpreted fault splays are downthrown and rotated relative to the sediments on either side. Other than applying some minor shifts to positioning and dip, the fault locations were nearly where expected and are now highly resolved from very near the surface to an approximate depth exceeding 100 feet.

4.2 HORIZON IDENTIFICATION

The shallower horizons on the shear wave dataset were constrained by Direct Push Testing (DPT) and Seismic Cone Penetrometer Testing (SCPT). This information became available after the seismic data had been processed, and the relevant locations are posted on the shear wave sections. Although the emphasis of the seismic study was to locate shallow faulting, the additional ground truth has been incorporated to facilitate horizon identification and explain some of the characteristics of the shallow seismic reflectors.

For reflecting horizons that lie below the intrusive tests, a different method of horizon identification was used. Velocity log data from the P-S Suspension logger **(Figure 6B)** clearly identify p- and s-wave velocities to approximately the level of limestone bedrock. The s-wave velocity data show a gradual increase in velocities from about 1,000 ft/s at a depth of 50 feet bgs to approximately 2,000 ft/s at a depth of approximately 370 feet bgs. Using the average s-wave velocity above the specific depth of a horizon provides an "expected" two-way travel time to that formation. (Note that an additional 70 msec must be added after multiplying by 2, to account for the time lag induced by the datum and correction velocity.)

Using this approach, the two-way travel times to the top of the Porters Creek Clay and McNairy Formations, and to the limestone bedrock were estimated in the s-wave sections; depths to the top of the later two were confirmed in the p-wave sections.

4.2.1 Loess

The shallowest reflectors on Lines 2S and 3S occur between 90 and 130 msec. The base of the shallowest reflectors has been picked and highlighted in yellow. The picked horizon is deemed to be near the base of the Loess at Site 3A.

The shallowest bright reflector on Line 2S **(Figure 15)** exists only on the east side of the section from shotpoints (SP) 670-890. There is no significant information in the DPT data to indicate changes in material properties that would produce this reflector. The DPT data from SP's 741 and 798 indicate that some gravels are present about 16-24 feet bgs, but they appear to be minimal. It's possible that some other lithologic character, such as clay content, is affecting rock "stiffness" to produce there reflectors.

On Line 3S **(Figure 16)**, a series of high amplitude peaks and troughs extend across the top of the section. This package of reflectors varies laterally in thickness, and appears to define near surface channel features on the east side of the section. It's not obvious from the DPT data what lithologic changes might be causing the reflectors observed along the top of this line. However, most of the DPT data along the line indicates the presence of sand and/or gravel layers on the order of 17-23 feet bgs. Thin, coarse-grained layers at these depths would likely produce the shallow reflectors observed on the sections.

4.2.2 Firm Sand

The SCPT and DPT data document the existence of a stiff sand layer at approximately 30-35 feet bgs. This firm sand (highlighted in blue) produces a strong reflector on the shear wave sections at approximately 150 msec. The "Firm Sand" reflector is certainly the dominant feature on Line 2S. On Line 3S, the Firm Sand manifests itself as a package of bright reflectors across the central part of the section, fading somewhat at both ends. DPT information along Line 3S indicates that the Firm Sand is not a single unit here, but represented by a series of interbedded hard sands and clays. The Firm Sand may represent channel or meander loop sedimentation, hence it might be expected to exhibit rapid lateral variations in character.

4.2.3 Porters Creek Clay Formation

The top of the Porters Creek Clay unit is fairly well constrained by intrusive testing. SCPT information and rotary boreholes extend down to the top of the Porters Creek within Site 3A, and this information has helped to identify the horizon on the seismic sections. To help confirm these findings, the s-wave travel time to horizon picked as the top of the Porters Creek was confirmed using the P-S Suspension log data. The calculation, which assumes an average s-wave velocity of 900 ft/s and depth to the Porters Creek of 60 feet, places the reflector at roughly 200 msec.

The intrusive information available indicates that the reflector seen on the shear wave sections is actually a gravelly sand layer directly overlying the Porters Creek Clay. SCPT data shows a large increase in tip stress and shear stress within this gravelly sand, and these properties are directly related to shear wave velocity. It appears that both the top and the bottom of the gravelly sand are being imaged on the shear wave sections, as evidenced by the peak-trough-peak sequence (blue-red-blue) seen on Line 3S. Since the top of the Porters Creek corresponds to the bottom of the gravelly sand, the lower peak has been picked on the seismic sections.

The top of the Porters Creek reflector is easily traced across the entirety of Line 3S. On Line 2S, the top of Porters Creek reflector is only evident on the eastern side of the line. Moving west from SP 785, the reflector gradually weakens and then disappears altogether. SCPT-9 provides a possible explanation for this appearance. At this location, the gravelly sand has bifurcated into two thin layers, each less than 2 feet thick. Tip Stress within these gravelly sands remains high, although shear stress shows less contrast than SCPT-8 on Line 3S. It is therefore likely that the gradual disappearance of the reflector as one moves west along Line 2S is at least partially due to the thinning and splitting of the gravelly sand.

4.2.4 Deep Reflector

On the s-wave sections **(Figures 15-16)**, a significant reflection identified as the "Deep Reflector" is evident from approximately 250-300 msec. The origin of this reflector could not be determined based on material properties shown in the Site 3A lithologic log (DB02). However, in the P-S Suspension log data **(Figure 6B)**, an increase in s-wave velocities of roughly 200 ft/s (i.e., ~20%) corresponds with the depth of this reflector at about 90 feet bgs in the central portion of Line 3S near the borehole.

The Deep Reflector occurs as a strong primary reflection on both Lines 2S and 3S. The Deep Reflector on Line 2S is quite obvious along the eastern half of the line, absent over the SP range 470-590, and reappears on the westernmost part of the section (SP's 340-460). The absence of the Deep Reflector over SP's 470-590 can be the result of several contributing factors. There seems to be a component of multiple interference within this zone, as a double bounce and triple bounce from the overlying Firm Sand is readily apparent on the section (the strong multiple here is due to focusing effects occurring at the Firm Sand level). Deteriorating surface conditions are also a contributing factor to the loss of the reflector in this zone. Finally, it's quite possible that changes in sedimentation provide a geologic basis for the loss of reflectance in this area.

The Deep Reflector is easily interpreted along most of Line 3S. However, over SP's 450-600, the interpreter has several horizons to choose from. The brightest reflector, which occurs at a time of 230 msec within this SP range, is suspiciously shallow and occurs near the end of the profile. Since there is no nearby well control, the true geologic relationships at this end of Line 3S are the subject of speculation.

4.2.5 McNairy Formation

On the p-wave sections **(Figures 13-14)**, the top of the McNairy Formation is interpreted to be within the range of 100-120 msec. Using an average s-wave velocity of 1,000 ft/s (from the P-S Suspension log) and assuming a depth of 160 feet bgs, two-way travel time calculations place the reflector at roughly 390 msec in the central portion of Line 3S near the borehole. Some subtle hints of the McNairy Formation may be evident near the bottom of both s-wave sections. However, due to survey design considerations and the importance of emphasizing the details seen in the target zone of this investigation, the data have been truncated at 400 msec (~180 feet bgs), and the McNairy Formation has not been interpreted.

4.2.6 Limestone

The Limestone interpreted on the p-wave sections **(Figures 13-14)** occurs at two-way travel times ranging from 165-180 msec. Using an average s-wave velocity of 1,250 ft/s (from the P-S Suspension log) and assuming a depth of 390 feet bgs, two-way travel time calculations place the reflector at roughly 700 msec in the central portion of Line 3S near the borehole. Hints of a probable Limestone reflector are present on both shear wave sections, but due to the survey design, they are weak and probably not correctly represented in time. For these reasons and to emphasize the details seen in the target zone, the shear wave sections have been truncated at 400 msec, and a Limestone reflector has not been interpreted.

4.3 FAULTING

The initial p-wave surveys completed at Site 3A revealed that the subsurface is fairly complex. Eleven generally NNE-trending faults were interpreted to show disruptions near the top of limestone bedrock that appear to offset that unit. Nine of the interpreted faults were thought to project above the limestone bedrock. Based on the p-wave seismic results, the area of investigation for the s-wave study was narrowed to focus on those interpreted faults that appear to extend upward into young sediments overlying bedrock, occur adjacent to or bound a significant anticline-type feature, and trend through the central portion of the site. **Figure 17** illustrates the faults interpreted from the p-wave data within the focus area of the s-wave survey. Note that fault locations are mapped at the top of the Limestone level. **Figure 18** illustrates the spatial distribution of faulting after analysis of the shear wave sections. On this figure, the fault locations are mapped where they intersect the Porters Creek reflector.

Differences in the two fault designations used to describe p-wave characteristics (e.g., Bedrock and Lower McNairy Formation only, and Bedrock and Unconsolidated Sediments) have been updated in **Figure 18** to include the interpreted s-wave results. As shown in **Figure 17**, Fault # 4 was previously highlighted in green (Bedrock and Unconsolidated Sediments) where it intersects Line 2S. Following s-wave data analysis, Fault # 4 is now thought to be an "older" feature (highlighted in blue) where it occurs along both Lines 2S and 3S. Previously, Fault # 5 was highlighted in blue (Bedrock and Lower McNairy Formation only). Following s-wave data analysis, Fault # 5 is now interpreted as a "younger" feature (highlighted in green) where it intersects both Lines 2S and 3S.

The s-wave sections have approximately twice the vertical resolution and 2.5 times the horizontal resolution of the p-wave sections. This increase in resolution, combined with the generally good data quality, allows for a different approach to fault interpretation than was used on the p-wave data. On the p-wave sections, instantaneous phase displays of stacked data were used to emphasize diffractions and discontinuities at the top of the McNairy and limestone bedrock levels. On the s-wave profiles, the interpretation was completed on migrated data (no reliance on diffractions), and faults were identified primarily by offsets in reflectors and velocity "sags." Velocity sags in s-wave data are often caused by perturbations in the local velocity field associated with fracturing. Velocity sags can be diagnostic, particularly when there is reasonable alignment and indicators of faulting above or below the sag.

The first step in mapping faults on the s-wave data was to transpose the interpreted faults from the p-wave sections. This was easily done, with the faults interpreted from p-wave data shadowed in white on the s-wave sections **(Figures 15-16)**. The p-wave interpreted faults generally occur in very close proximity to obvious fault related features on the s-wave sections. Some small adjustments were made to positioning the faults due to the increased resolution provided in the shear wave data. The final interpreted faults are shown in pink.

Faults that are evident in the s-wave data, but were not seen on the p-wave sections, are shown in orange on Lines 2S and 3S.

Overall, the s-wave sections confirm the faults interpreted from the p-wave data. Therefore, the same fault numbering system used in the p-wave study can also be utilized here. The s-wave data provides complimentary information on Faults 4-8 **(Figures 17-18)**.

4.3.1 Fault # 3A

Fault # 4 was originally interpreted from the p-wave data to include a southwest-trending splay south of Line 2 **(Figure 17)**. With the additional resolution provided by the s-wave data, it now appears that there are two separate faults here **(Figure 18)**. The westernmost fault has been labeled "3A," as it did not previously exist as a separate entity. On Line 2S **(Figure 15)**, the fault indicators on the s-wave section are relatively weak, therefore the fault plane is dashed. However, a sudden change in the Deep Reflector is evident, as well as a small potential offset in the Firm Sand reflector.

4.3.2 Fault # 4

This fault was interpreted from the p-wave sections to intersect the Porters Creek on Line 2S at approximately SP 530 and bound the significant anticline-type feature along the west. However, the Porters Creek reflector in this part of Line 2S is obscured by multiples, and data quality is diminished by poor surface conditions **(Figure 15)**. The s-wave interpreted fault is shifted slightly west from its original position, but the seismic indicators for the exact fault position are not obvious within this zone. Although confidence is high that there is a fault in the immediate vicinity of the location shown, Fault # 4 is dashed to indicate the uncertainty in positioning. There are no significant anomalies in the seismic data to indicate that Fault # 4 extends up to the Firm Sand.

4.3.3 Fault # 5

Fault # 5 was interpreted from the p-wave sections to be truncated beneath the McNairy unit **(Figure 13)**. The additional resolution provided in the s-wave data now contradicts this view. Fault # 5 is interpreted to extend upward through the Porters Creek and Firm Sand. Disrupted reflectors occur at the Deep Reflector and Porters Creek levels, and velocity sags are interpreted at the Firm Sand level **(Figure 15)**. The shear wave expression of this fault is slightly west of its original, projected p-wave position (highlighted in white).

4.3.4 Fault # 6

Fault # 6 is the only fault expected to be imaged on both Lines 2S and 3S **(Figure 17)**. The overall fault "signature" as it appears on both lines is quite similar. The fault plane is rotated slightly on Line 2S, and shifted slightly east on Line 3S, relative to the original p-wave interpretation. In addition, splay faults are evident on both s-wave sections above the Deep Reflector level (this was not apparent on the p-wave data). This fault is interpreted to be coincident with the eastern boundary of the significant anticline-type structure identified in the original p-wave data.

On Line 2S **(Figure 15)**, the fault is defined by offset reflectors that are clearly evident at the Deep Reflector level. At the Porters Creek, faulting is not as well defined, but there is an abrupt change in reflector character in the vicinity of where this fault should be. As discussed earlier, SCPT data indicates that variations in Porters Creek sedimentation may be occurring here. At the Firm Sand and Loess levels, localized dips in the reflector may be velocity sags, indicating fault induced velocity variations.

Fault # 6 is evident on Line 3S **(Figure 16)** by offsets or otherwise disrupted reflectors at all levels. Nearby and to the west of the p-wave interpreted fault (highlighted in white), another fault and accompanying splay are newly interpreted. This new fault is interpreted to occur along the eastern flank of the anticline-type feature. Since this new fault is not evident on Line 2S, it appears that Fault # 6 bifurcates into a series of narrow horsts and grabens as it trends south **(Figure 18)**.

4.3.5 Fault # 7

Fault # 7 occurs at roughly SP 840 (Porters Creek level) on Line 3S. Based on previous work, this fault is expected to occur east of Line 2S, and hence not be seen. The position of this fault is shifted slightly to the west from the original interpretation, and it is clearly evidenced on the s-wave section by offset reflectors at the Deep Reflector and Porters Creek level. There is no indication that this fault extends upward to the Firm Sand.

4.3.6 Fault # 8

Fault # 8 on the p-wave interpretation was imaged once again on Line 3S. This fault is the easternmost in the s-wave study area, and based on the previous work, is not expected to be seen on Line 2S. On **Figure 16**, the revised position of Fault # 8 is slightly to the east and a splay fault is evident below the Porters Creek level, extending east from the main fault plane. The fault is indicated by offset reflectors at the Deep Reflector and Porters Creek levels, and by localized discontinuities in reflectors at the Firm Sand level. Above the Firm Sand, the interpretation becomes less certain, although small discontinuities at the Loess level may indicate that faulting extends through these sediments. Like most of the faults in this area, relative movement along the main fault plane is normal, with the downthrown side to the east. Sediments within the splay are downthrown and rotated relative to the sediments on either side.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The shear wave seismic reflection survey was successful in imaging several horizons and faults beneath Site 3A. Horizons evident in the s-wave data include the Loess (~10-20 feet bgs), Firm Sand (~25-35 feet bgs), Porters Creek Clay Formation (~35-60 feet bgs), and a horizon identified as the "Deep Reflector" (~70-90 feet bgs). Overall, the s-wave profiles support the general conclusions derived from the earlier p-wave study.

For most of the faults in this area, relative movement along the main fault plane is normal, with the downthrown side to the east. These normal faults, along with their associated splays, either form a series of narrow horst and graben features, or divide the local sediments into a series of rotated blocks. Both are consistent with extensional regional tectonics and faulting observed in the Fluorspar Area Fault Complex of Massac County, Illinois, located just across the Ohio River. Most of the faults identified in the p-wave data that were selected for further characterization using shear waves have been confirmed to extend upward into younger sediments overlying limestone bedrock.

Strong, coherent reflectors are evident down to the expected level of the Deep Reflector, although hints of reflections from the top of the McNairy Formation and Limestone are evident. Intrusive information and borehole velocity log data generally correlates these reflection events to stiff sands, gravelly sand layers, or local changes in formation velocities. Of prime importance to the s-wave investigation is that young faulting (above the McNairy Formation) is indicated on the seismic sections by: (a) abrupt terminations of reflectors, (b) changes in dip, (c) localized velocity "sags" due to the influence of broken rock on the speed of shear wave propagation, and (d) offsets in reflecting horizons. Young faulting is evident on the shear wave sections, and the profiles provide target areas for further intrusive investigations.

6.0 CERTIFICATION

All geophysical data analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by Blackhawk GeoServices senior geophysicists.

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* This geophysical investigation was conducted using sound scientific principles and state-of-the-art technology. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing, interpretation, and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review.

A geophysicist's certification of interpreted geophysical conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations, or ordinances.

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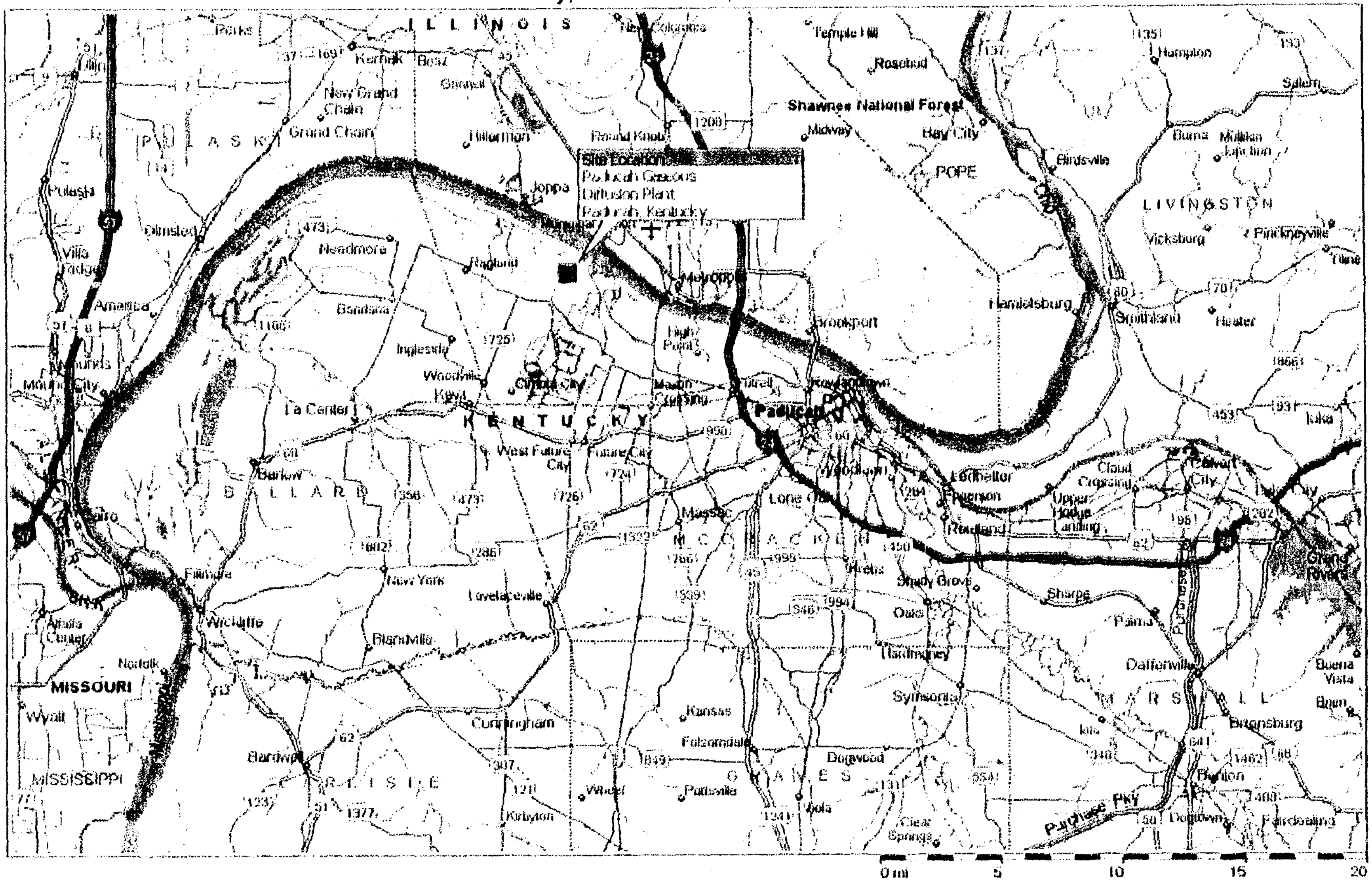
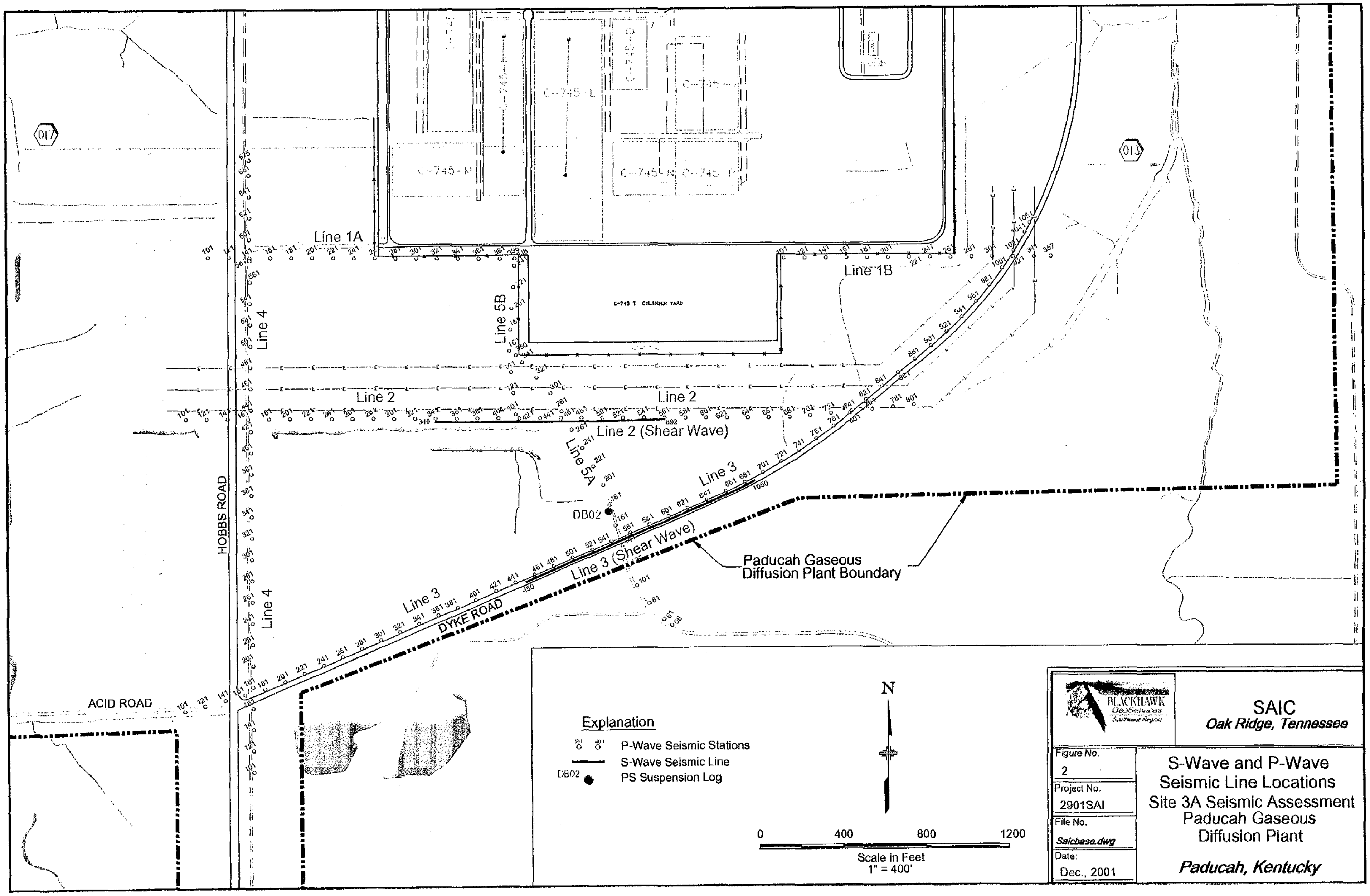
Kentucky, United States, North America



BLACKHAWK GeoServices Southeast Region	**Site Location Map** *Paducah Gaseous Diffusion Plant* *Paducah, Kentucky*	Figure: 1 Project: 2901SAI \projects\2901sai\SiteMap.cdr



SAIC
Oak Ridge, Tennessee

Figure No. 2

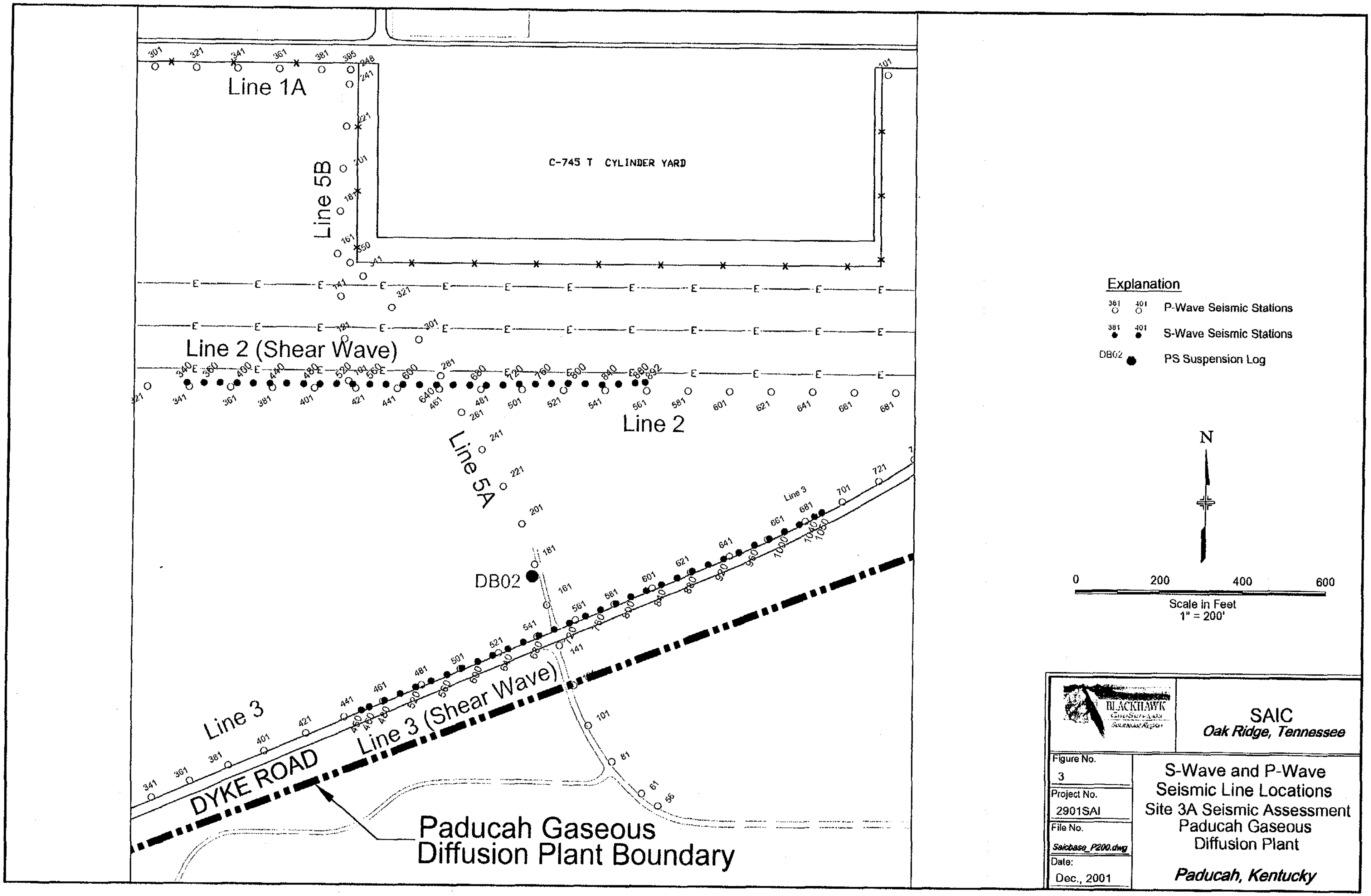
Project No. 2901SAI

File No. Saicbase.dwg

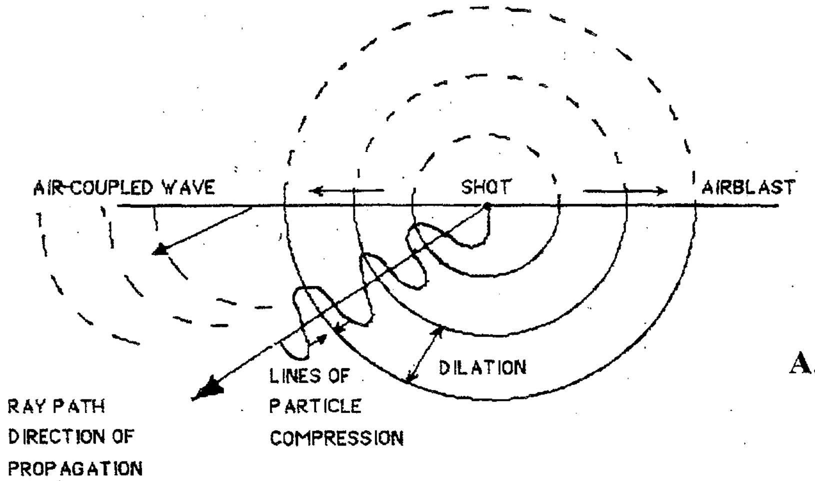
Date: Dec., 2001

S-Wave and P-Wave Seismic Line Locations
Site 3A Seismic Assessment
Paducah Gaseous Diffusion Plant

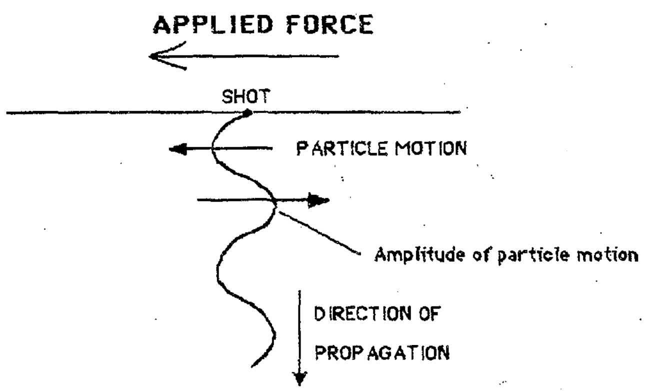
Paducah, Kentucky



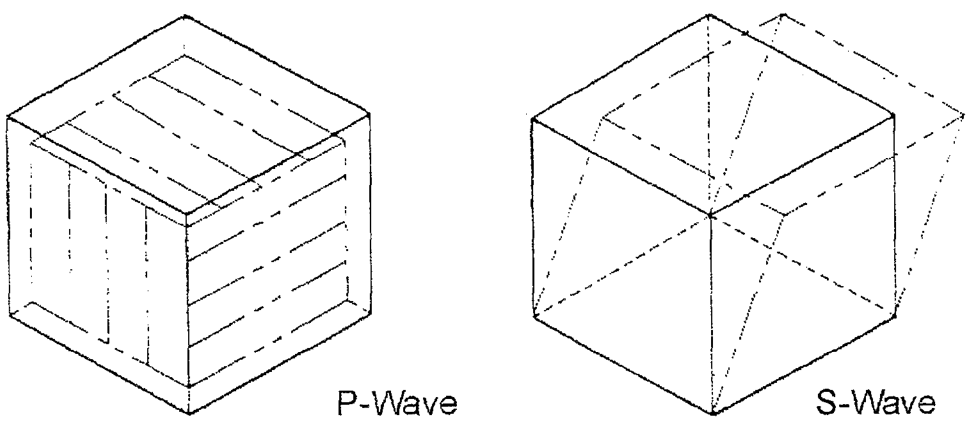
Line 1A
C-745 T CYLINDER YARD
Line 5B
Line 2 (Shear Wave)
Line 2
Line 5A
DB02
Line 3
Line 3 (Shear Wave)
DYKE ROAD
Paducah Gaseous Diffusion Plant Boundary
Explanation
P-Wave Seismic Stations
S-Wave Seismic Stations
PS Suspension Log
N
0 200 400 600
Scale in Feet
1" = 200'
SAIC
Oak Ridge, Tennessee
Figure No.
3
Project No.
2901SAI
File No.
Saicbase_P200.dwg
Date:
Dec., 2001
S-Wave and P-Wave Seismic Line Locations
Site 3A Seismic Assessment
Paducah Gaseous Diffusion Plant
Paducah, Kentucky



A. Compressional Wave Transmission (Evans 1997).



B. Shear Wave Generation (Evans 1997).



C. Parcel Deformation Caused by P- and S- Waves (Helbig 1987).

BLACKHAWK GeoServices Southeast Region

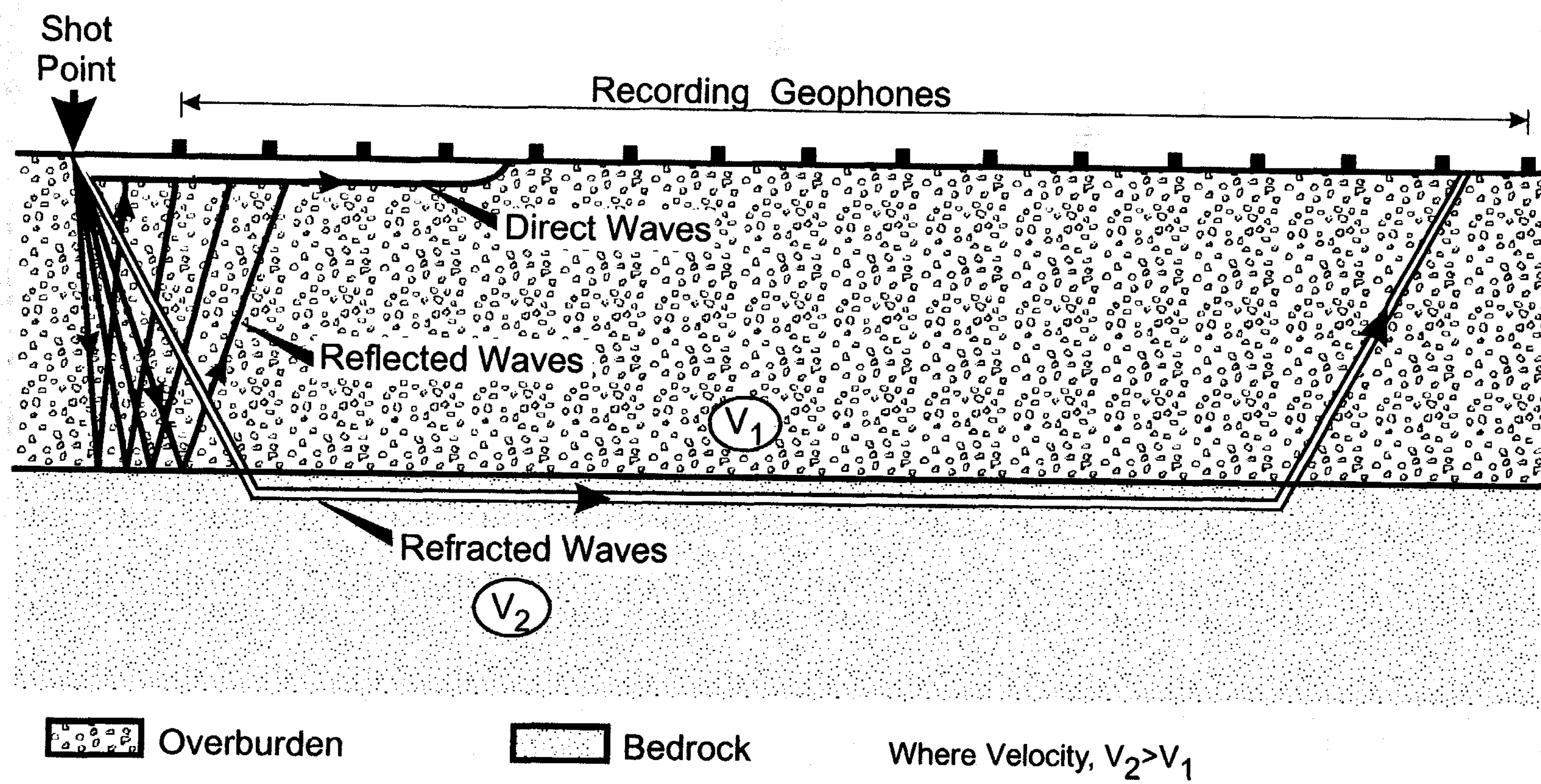
P- and S-Wave Transmission and Parcel Deformation

Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Figure: 4

Project No. 2901SAI

\projects\2901sai\ps-wave_transmission.cdr



BLACKHAWK GeoServices Southeast Region

Seismic Raypath Geometry

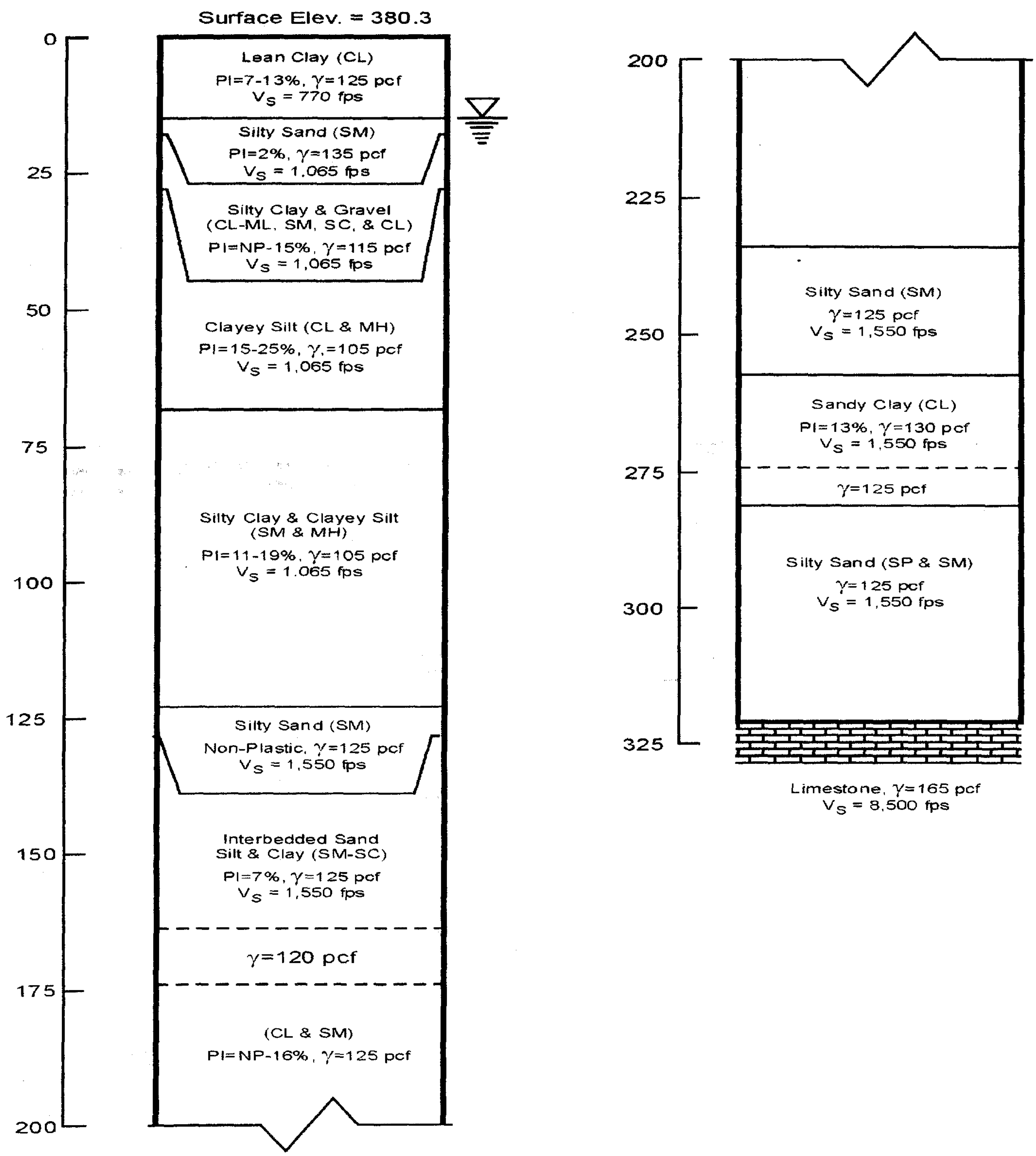
Paducah Gaseous Diffusion Plant

Paducah, Kentucky

Figure: 5

Project: 2901SAI

\projects\2901sai\Raypath.cdr



Note: Information provided by SAIC.

BLACKHAWK GeoServices Southeast Region

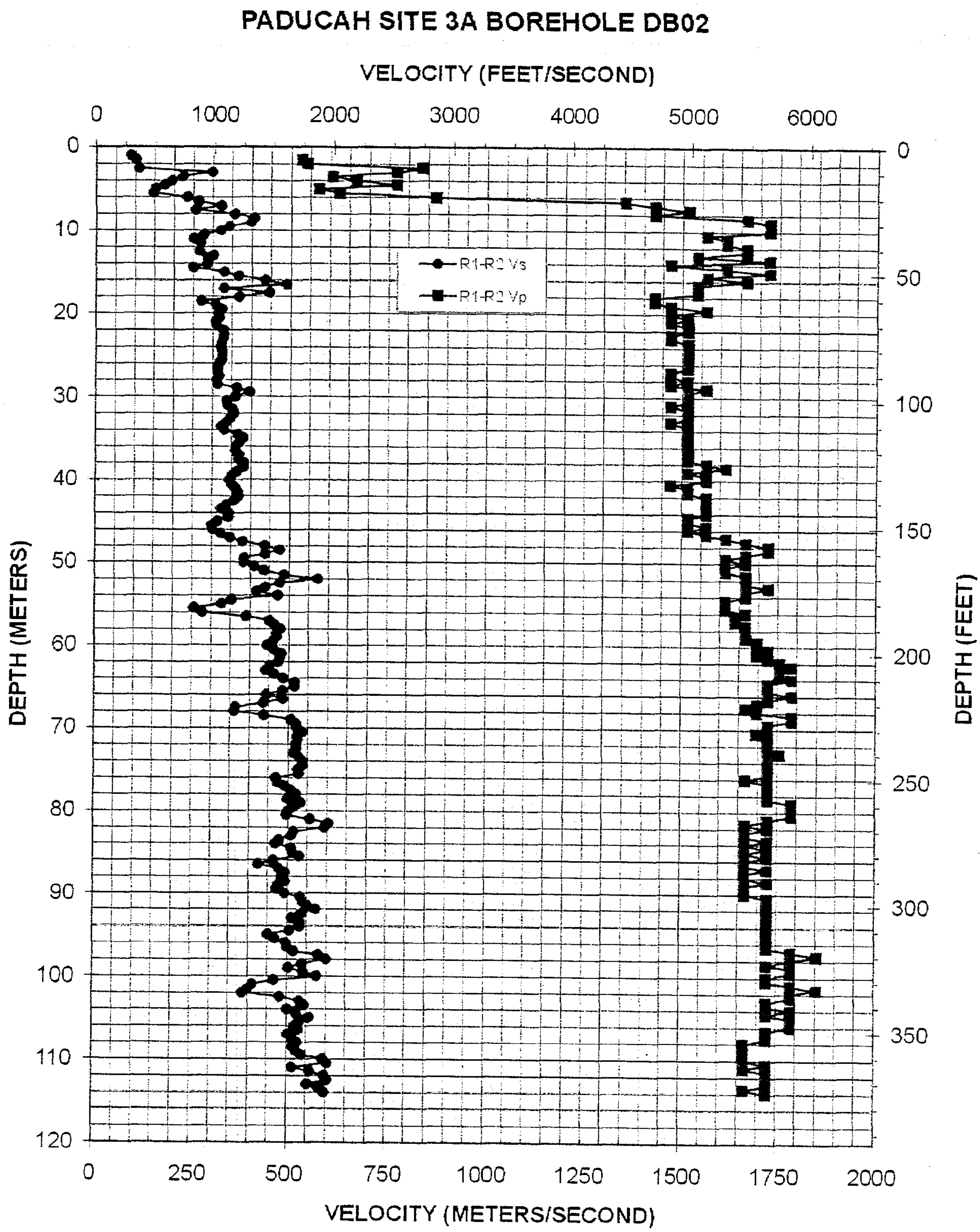
PGDP Stratigraphy and Shear Wave Velocities

Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Figure: 6A

Project No. 2901SAI

2901sai\PGDP_stratigraphy_velocities.cdr



BLACKHAWK GeoServices Southeast Region

P-S Suspension Log Velocities

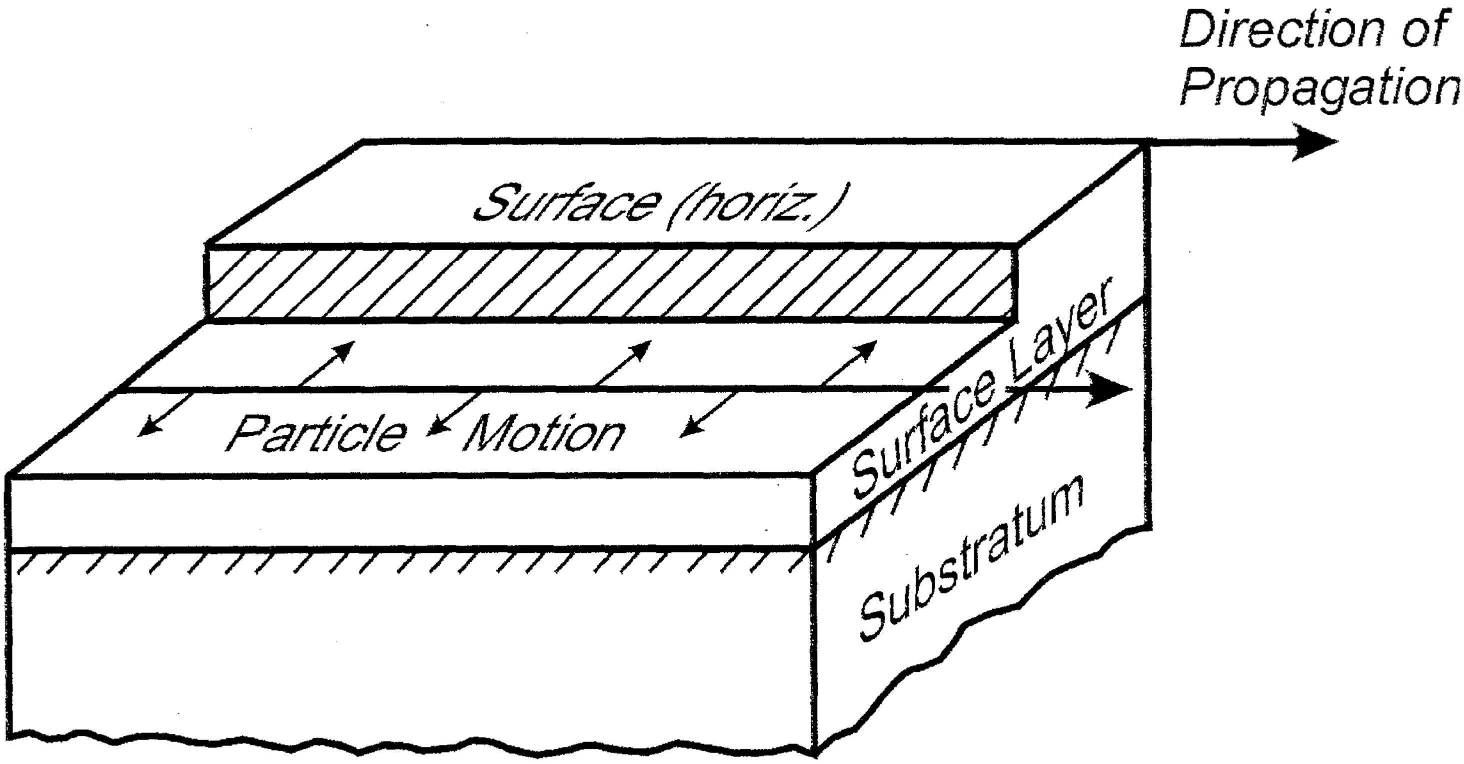
Paducah Gaseous Diffusion Plant

Paducah, Kentucky

Figure: 6B

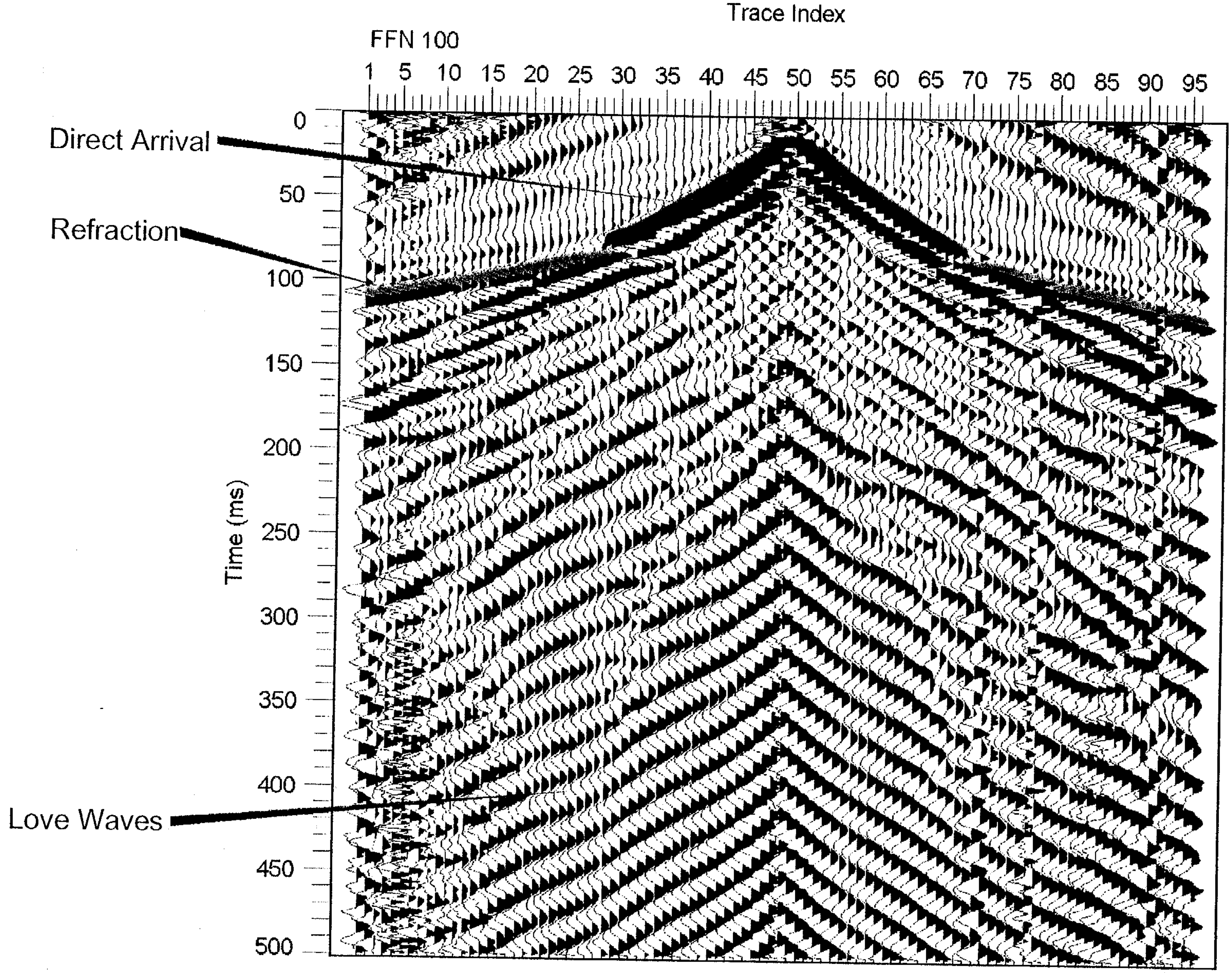
Project No. 2901SAI

2901sai\PGDP_suspension_log.cdr



Love Waves traveling along the surface of a solid (Dobrin 1976).

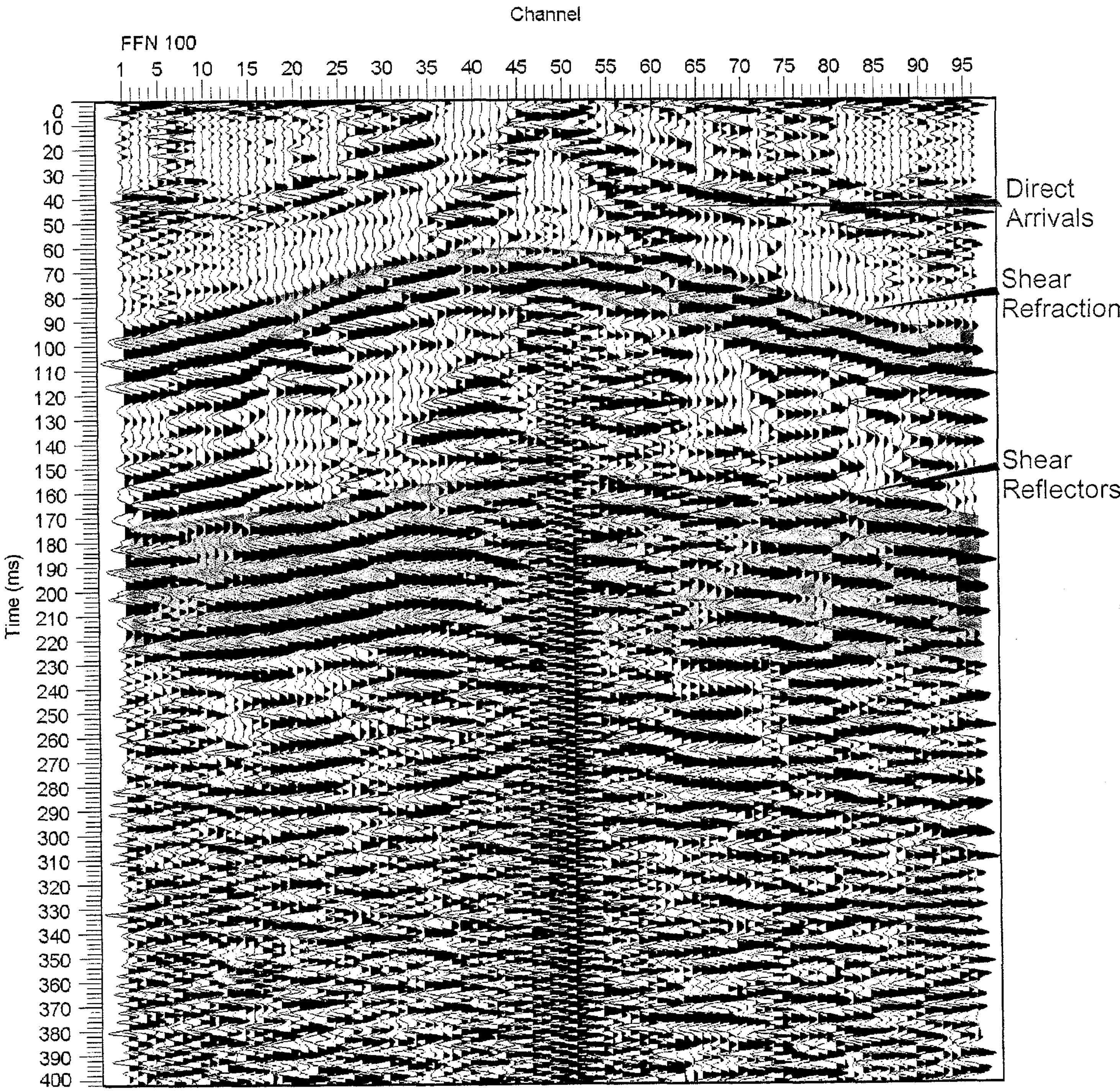
BLACKHAWK GeoServices Southeast Region	**Love Wave Particle Motion** *Paducah Gaseous Diffusion Plant* *Paducah, Kentucky*	Figure: 7 Project No. 2901SAI 2901sai\love_waves.cdr



BLACKHAWK GeoServices Southeast Region

Sample Shear Wave Shot Record (Raw)
(Line 3, FFID 100)
Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Figure: 8	
Project: 2901SAI	
\projects\2901sai\Shot_Record.cdr	



BLACKHAWK GeoServices Southeast Region

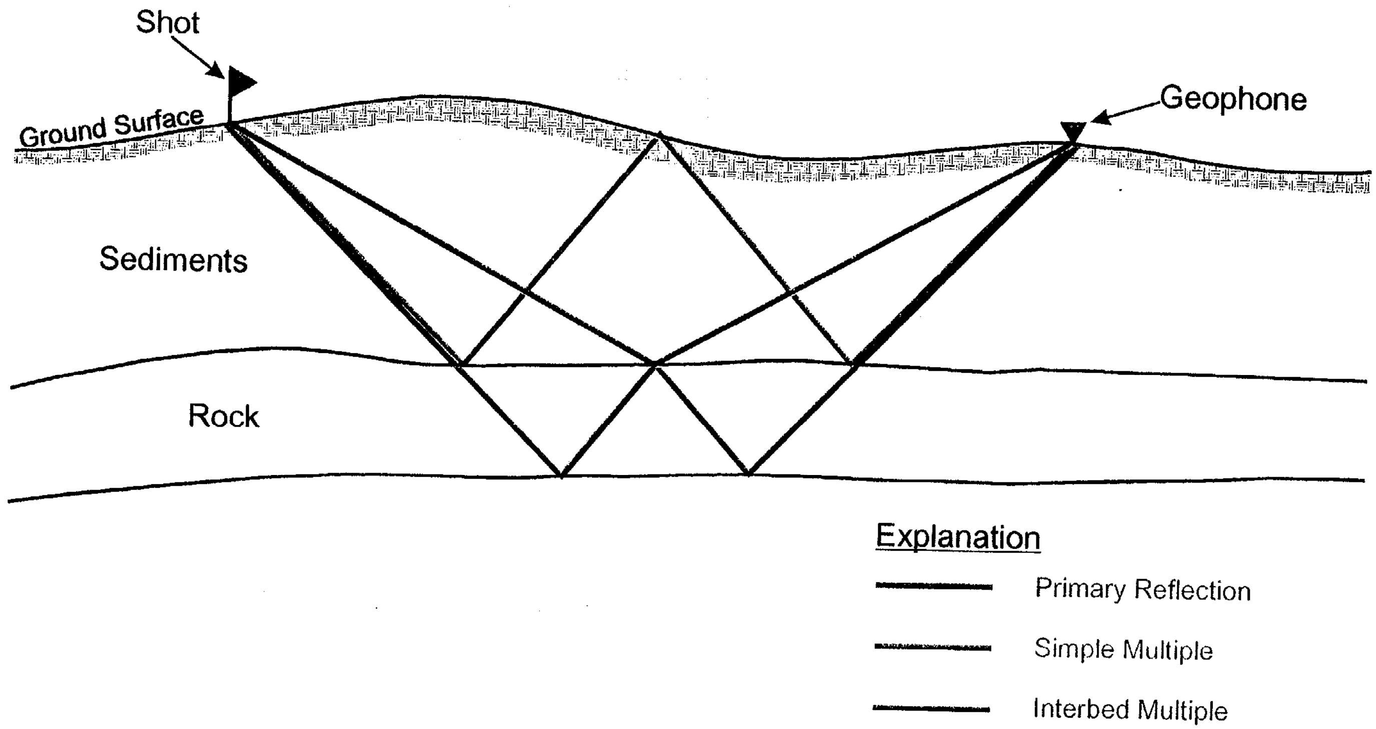
Sample Shot Record After Love Wave Removal

Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Figure: 9

Project No. 2901SAI

\projects\2901sai\Shot_Record_Love.cdr



BLACKHAWK GeoServices Southeast Region

Raypaths of Simple and Interbedded Multiples in the Seismic Reflection Data

Paducah Gaseous Diffusion Plant

Paducah, Kentucky

Figure: 10

Project: 2901SAI

|projects\2901sai\Spreads.cdr

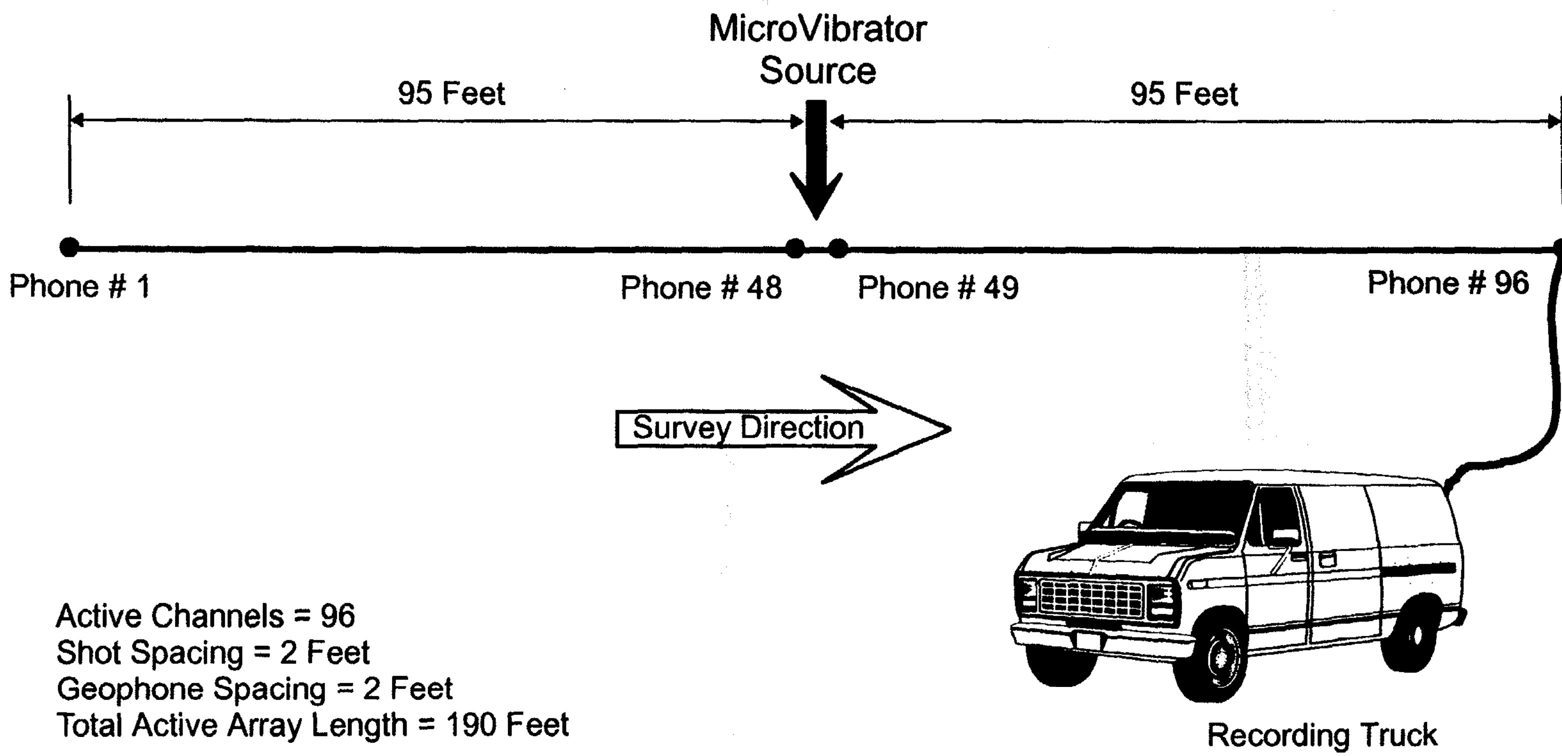
BLACKHAWK
GeoServices
Southeast Region

Bay MicroVibrator
Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Figure: 11

Project No. 2901SAI

2901sai\bay_microvibrator.cdr



Active Channels = 96
Shot Spacing = 2 Feet
Geophone Spacing = 2 Feet
Total Active Array Length = 190 Feet

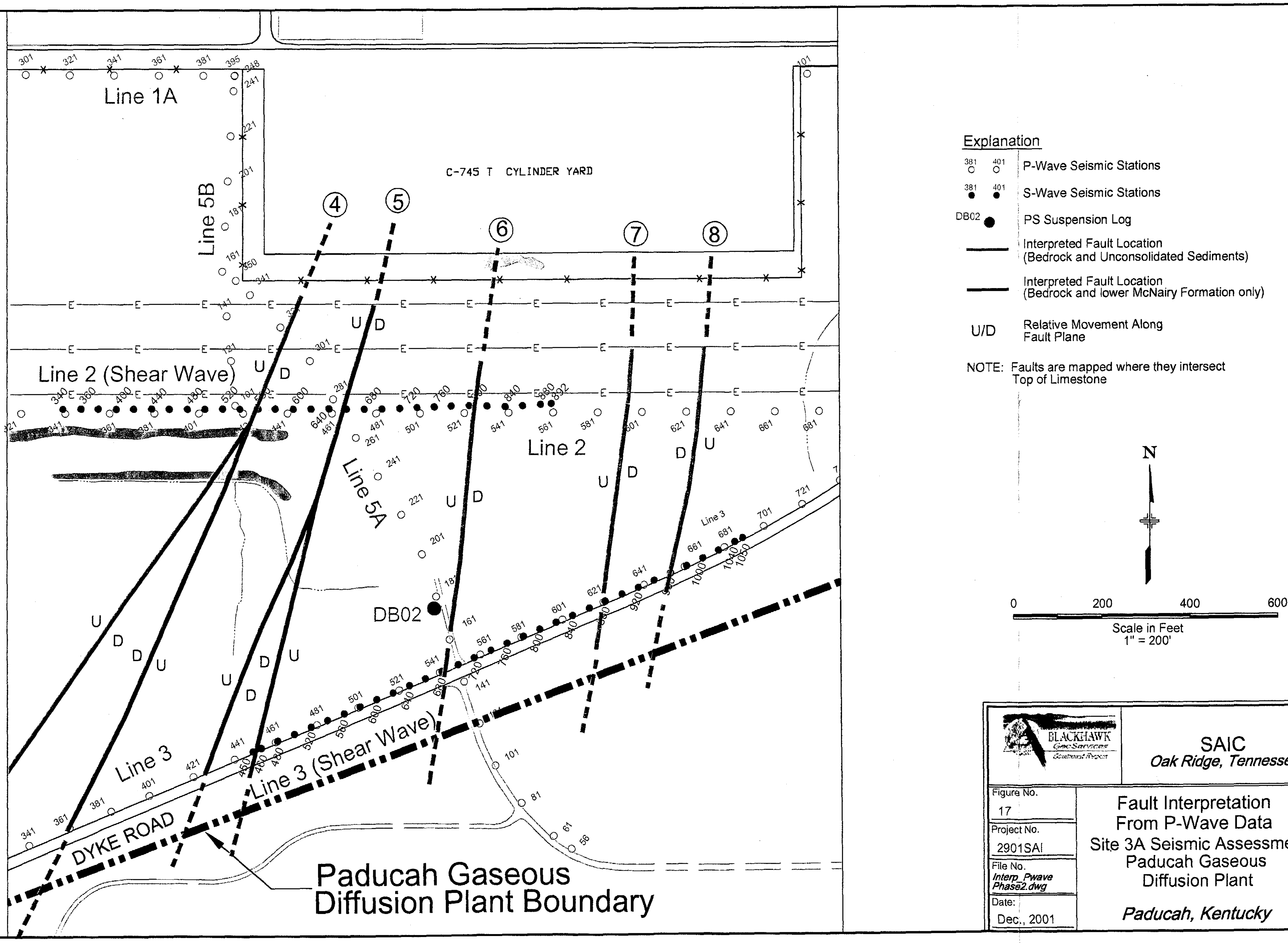
BLACKHAWK GeoServices Southeast Region

Diagram of Nominal
Shear Wave Acquisition Geometry
Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Figure: 12

Project: 2901SAI

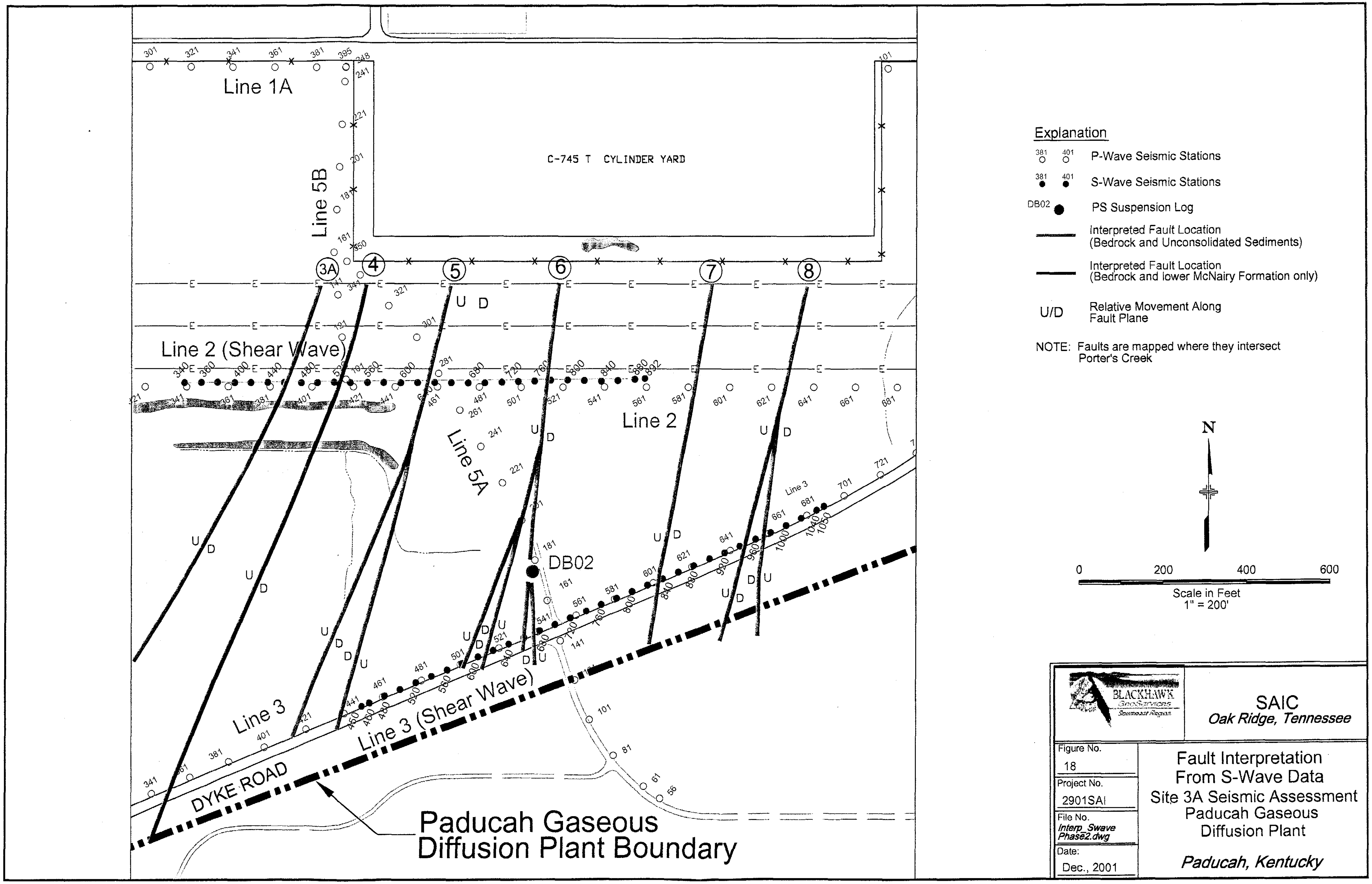
|projects\2901sai\SpreadReflec.cdr



BLACKHAWK GeoServices

SAIC
Oak Ridge, Tennessee

Figure No. 17	Fault Interpretation From P-Wave Data Site 3A Seismic Assessment Paducah Gaseous Diffusion Plant
Project No. 2901SAI	
File No. *Interp_Pwave Phase2.dwg*	
Date: Dec., 2001	*Paducah, Kentucky*



SAIC
Oak Ridge, Tennessee

Figure No. 18	Fault Interpretation From S-Wave Data
Project No. 2901SAI	Site 3A Seismic Assessment
File No. *Interp_Swave Phase2.dwg*	Paducah Gaseous Diffusion Plant
Date: Dec., 2001	*Paducah, Kentucky*

ATTACHMENT D-1

APPENDIX A

ATTACHMENT D-II

DPT SURVEY RESULTS: DRILLING LOGS

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LITHOLOGIC LOG	BORING/WELL NO: DPT-400L2	PAGE 1 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 14:25 on 02-26-02	Drill End (time/date): 15:20 on 02-26-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 32 ft
Logged By: T. Campbell	Coordinates: E -3604.38 N -6701.73	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
									Ground elevation = 368.75 ft amsl
		01	2.8	NA	–	–	Silt (ML), pale yellowish brown (10YR6/2), very soft to soft, becoming harder with depth, wet		Trace Clay Trace organics
5		02	2.3	NA	–	–	Silt (ML) as above		Trace organics Trace manganese oxide
10		03	3.0	NA	–	–	Silt (ML) as above		Trace organics Organics at 10.5-10.6 ft
15		04	3.6	NA	–	–	Silt (ML), indistinct mottling grades from dark yellowish orange (10YR6/6) to pale yellowish brown (10YR6/2), soft, moist		20% Clay Trace Sand Trace fine Gravel
		05	4.0	NA	–	–	Silt (ML) as above		
							Silt (ML) as above but hard		Angular to subangular Gravel, increased Clay content
							Poorly Graded Gravel with Sand and Silt, colored as above		Fine to coarse Gravel, angular, flattened, elongated Fine to coarse Sand, elongated
							Silt (ML) as 18.5-18.6 ft		
20							Silt (ML), moderate reddish brown (10R4/6)		50% Sand
		06	2.8	NA	–	–	Poorly Graded Gravel with Sand and Silt (GP-GM), Sand and Silt content greater than 18.8-19.1 ft		Fine to coarse Gravel, angular, flattened, elongated Fine to coarse Sand, elongated
25		07	2.8	NA	–	–	Grading to Poorly Graded Sand with Silt (SP-SM), dark yellowish orange (10YR6/6), moist, with blebs of Clayey Silt (ML), medium plasticity, pale yellowish brown (10YR7/2), moist		Fine Sand, subrounded to subangular Gravel layer at 25.3-25.5 ft
							Poorly Graded Sand with Silt (SP-SM) as above		
30		08	2.8	NA	–	–	Poorly Graded Sand with Silt (SP-SM), dark yellowish orange (10YR6/6) to pale yellowish brown (10YR6/2) with trace moderate reddish brown (10R4/6), very soft to soft, moist		Fine sand, subangular to subrounded Trace mica

LITHOLOGIC LOG	BORING/WELL NO: DPT-400L2	PAGE 2 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 14:25 on 02-26-02	Drill End (time/date): 15:20 on 02-26-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 32 ft
Logged By: T. Campbell	Coordinates: E -3604.38 N -6701.73	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
		08	--	NA	–	–	Poorly Graded Sand with Silt (SP-SM), dark yellowish orange (10YR6/6) to pale yellowish brown (10YR6/2) with trace moderate reddish brown (10R4/6), very soft to soft, moist		Fine sand, subangular to subrounded Trace mica
							Poorly Graded Gravel with Sand (GP), wet		Fine to coarse Sand and Gravel, angular to rounded
									Total Depth = 32.0 ft
35									

Prepared by: Kenneth R. Davis — Kenneth R. Davis — 07-19-02 — Date

Checked by: Michelle R. Blanton — 07/23/02 — Date

Approved by: Bruce J. Haas — 07/29/02 — Date

LITHOLOGIC LOG	BORING/WELL NO: DPT-440L2	PAGE 1 of 1
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 13:40 on 02-25-02	Drill End (time/date): 14:30 on 02-25-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 21.6 ft (Refusal)
Logged By: T. Campbell	Coordinates: E -3404.98 N -6711.16	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
		01	4.0	NA	–	–	Fill: Silt, Sand, road Gravel		Ground elevation = 392.74 ft amsl
							Silt (ML), nonplastic, dark yellowish brown (10YR5/2) to moderate yellowish brown (10YR5/4), hard, moist		Trace fine Sand Trace organics Trace manganese oxide
5		02	3.1	NA	–	–	Silt (ML) as above Below 4.2 ft, becoming mottled dark yellowish orange (10YR6/6) and light gray (N7)		Trace manganese oxide
10		03	4.0	NA	–	–	Silt (ML) as above		Light gray mottled areas are soft Vertical mottle at 10.0-10.4 ft, probably random
15		04	4.0	NA	–	–	Silt (ML), nonplastic, light brown (5YR5/6) to dark yellowish orange (10YR6/6), hard, moist Below 14.5 ft, becoming mottled with pale yellowish brown (10YR6/2)		Trace manganese oxide Trace Gravel
		05	4.0	NA	–	–	Silt (ML) as above		
							Silt with Sand (ML), mottled light brown (5YR5/6), grayish orange (10YR7/4), and light gray (N7), hard, moist		Light brown areas: 30% fine Sand, subangular to subrounded, trace flat grains Light gray areas: 10% fine Sand, few silty clay balls High angle mottle at 19 ft
20		06	1.0	NA	–	–	Poorly Graded Sand with Silt (SP-SM), pinkish gray (5R8/1), hard, dry to moist		20% Silt Very fine Sand Total Depth = 21.6 ft
25									

Prepared by: Kenneth R. Davis   Kenneth R. Davis   07-19-02 Date

Checked by: M R Blanton   Michelle R. Blanton   07/23/02 Date

Approved by: Bruce J. Haas   Bruce J. Haas   07/29/02 Date

LITHOLOGIC LOG	BORING/WELL NO: DPT-500L2	PAGE 1 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 14:55 on 02-25-02	Drill End (time/date): 16:00 on 02-25-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 32 ft
Logged By: T. Campbell	Coordinates: E -3104.51 N -6739.18	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
									Ground elevation = 393.39 ft amsl
		01	3.2	NA	–	–	Silt (ML), nonplastic, light olive gray (5Y6/1) to dark greenish gray (5GY4/1), soft, wet		Grass at surface Trace fine Sand
5		02	3.6	NA	–	–	Silt (ML) as above but hard		
10		03	2.9	NA	–	–	Silt (ML) as above but damp		Trace manganese oxide
15		04	3.9	NA	–	–	Silt (ML) as above, indistinctly mottled dark yellowish orange (10YR6/6) and pale yellowish brown (10YR6/2), hard, moist		
20		05	3.9	NA	–	–	Silt (ML), low to medium plasticity, mottled dark yellowish orange (10YR6/6) and pale yellowish brown (10YR6/2), hard, moist		30 % Clay Trace fine to coarse Gravel, subangular to subrounded
		06	4.0	NA	–	–	Silt (ML) as above		
25		07	4.0	NA	–	–	Silt (ML) as above but with decreasing Clay content and increasing Sand content, nonplastic, moist		Fine Sand Trace fine Gravel, angular to rounded High angle mottle at 25.4 ft, probably random
30		08	4.0	NA	–	–	Silt (ML) as above but with decreasing sand content (grading to clayey silt), hard, moist		Trace moderate reddish brown (10YR4/6) Gravel, subangular to subrounded

LITHOLOGIC LOG	BORING/WELL NO: DPT-500L2	PAGE 2 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 14:55 on 02-25-02	Drill End (time/date): 16:00 on 02-25-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 32 ft
Logged By: T. Campbell	Coordinates: E -3104.51 N -6739.18	Protective Level: D

DEPTH (ft)	SAMPLE			SPT RESULT	HEALTH/ SAFETY		LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
	INTERVAL	NUMBER	RECOVERY (ft)	6"-6"-6"-6" (N)	VOC	RAD			
		08	4.0	NA	--	--	Silt (ML) as at 24-28 ft but with decreasing sand content (grading to clayey silt), hard, moist		Trace moderate reddish brown (10YR4/6) Gravel, subangular to subrounded Total Depth = 32.0 ft
35									

Prepared by: Kenneth R. Davis — Kenneth R. Davis — 07-19-02 Date

Checked by: Michelle R. Blanton — Date 07/23/02

Approved by: Bruce J. Haas — 07/29/02 Date

LITHOLOGIC LOG	BORING/WELL NO: DPT-523L2	PAGE 1 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 11:10 on 02-26-02	Drill End (time/date): 12:15 on 02-26-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 32 ft
Logged By: T. Campbell	Coordinates: E -2986.55 N -6745.75	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
									<u>Ground elevation = 393.22 ft amsl</u>
		01	2.2	NA	–	–	Silt (ML), mottled dark yellowish orange (10YR6/6) and moderate yellowish brown (10YR5/4), hard, moist		Sample liner broke. Lost 1.8 ft of sample.
5		02	3.6	NA	–	–	Silt (ML) as above		Trace organics, especially 4-5 ft and 6.5 ft
10		03	2.6	NA	–	–	Silt (ML) as above but firm		Trace coarse sand, subrounded Trace manganese oxide
15		04	3.9	NA	–	–	Silt (ML) as above, mottling becoming more distinct		Trace organics (?) at 13.3-13.4 ft
		05	3.9	NA	–	–	Grading to Clayey Silt (ML), medium plasticity, colored as above, hard, moist		30 % Clay Trace-10% (increasing with depth) fine Gravel, angular to subangular
20		06	3.8	NA	–	–	*Mottled Sandy Silt with Clay (ML) and Clayey Silt (ML)*		Sandy Silt with Clay, hard: 30% Silt 20% Clay Trace fine gravel Sand and Gravel - subangular to subrounded Clayey Silt, medium plasticity, pale yellowish brown (10R6/2), moist: 30% Clay Trace fine gravel, angular to subrounded
25		07	3.8	NA	–	–	Silt (ML) as above but with trace moderate reddish brown (10R4/6)		
30		08	3.8	NA	–	–	Silt (ML), nonplastic, mottled dark yellowish orange (10YR6/6) and pale yellowish brown (10YR6/2), mottling becoming more distinct with depth, hard, moist		Trace medium to coarse Sand, subrounded

LITHOLOGIC LOG	BORING/WELL NO: DPT-523L2	PAGE 2 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 11:10 on 02-26-02	Drill End (time/date): 12:15 on 02-26-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 32 ft
Logged By: T. Campbell	Coordinates: E -2986.55 N -6745.75	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
		08	3.8	NA	–	–	Silt (ML), nonplastic, mottled dark yellowish orange (10YR6/6) and pale yellowish brown (10YR6/2), mottling becoming more distinct with depth, hard, moist		Trace medium to coarse Sand, subrounded Total Depth = 32.0 ft
35									

Prepared by: Kenneth R. Davis — Kenneth R. Davis — 07-19-02 Date

Checked by: [signature] — Michelle R. Blanton — 07/23/02 Date

Approved by: [signature] — Bruce J. Haas — 07/29/02 Date

LITHOLOGIC LOG	BORING/WELL NO: DPT-490L3	PAGE 1 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 08:00 on 02-25-02	Drill End (time/date): 09:40 on 02-25-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 42 ft
Logged By: T. Campbell	Coordinates: E -3297.26 N -7386.59	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
							Silt (ML), nonplastic, moderate yellowish brown (10YR5/4) to dark yellowish orange (10YR6/6), moist		Ground elevation = 400.65 ft amsl Grass at land surface Trace fine Sand
				Hand Augered	–	–	Silt (ML) as above but with very light gray (N8)		Trace organics. Organics decreasing with depth. No occurrence below 4 ft
5							Silt (ML) as above but light brown (5YR5/6)		
10		01	4.0	NA	–	–	Silt (ML) as above but without Sand		Trace manganese oxide
		02	3.9	NA	–	–	Silt (ML) as above, mottling indistinct		Trace manganese oxide
15		03	3.8	NA	–	–	Silt (ML), low to medium plasticity, mottled dark yellowish orange (10YR6/6) and pale yellowish brown (10YR6/2), hard, moist		15-25% Clay Trace fine Gravel, angular to subangular
							Sandy Silt (ML), colored as above with moderate reddish brown (10R4/6), hard, moist		Fine Sand, angular to subangular Trace fine Gravel
20		04	4.0	NA	–	–	Sandy Silt (ML) as above with decreasing moderate reddish brown (10R4/6)		
							Sandy Silt (ML) as above		
25		05	4.0	NA	–	–	Clayey Silt (ML), medium plasticity, mottled dark yellowish orange (10YR6/6) and pale yellowish brown (10YR6/2), hard, moist		Trace fine Sand
30		06	4.0	NA	–	–	Poorly Graded Sand with Silt (SP-SM), nonplastic, colored as above, hard, moist		Fine Sand 40% Silt Trace fine Gravel, angular

LITHOLOGIC LOG	BORING/WELL NO: DPT-490L3	PAGE 2 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 08:00 on 02-25-02	Drill End (time/date): 09:40 on 02-25-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 42 ft
Logged By: T. Campbell	Coordinates: E -3297.26 N -7386.59	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
							Poorly Graded Sand with Silt (SP-SM), nonplastic, mottled dark yellowish orange (10YR6/6) and pale yellowish brown (10YR6/2), hard, moist		Fine Sand 40% Silt Trace fine Gravel, subrounded
		07	3.0	NA	–	–	Poorly Graded Sand with Silt and Clay (SP-SM/SC), moderate yellowish brown (10R4/6) to very dark red (5R2/6), soft to very soft		Trace mica
							Poorly Graded Sand with Silt (SP-SM), nonplastic, mottled dark yellowish orange (10YR6/6) and pale yellowish brown (10YR6/2), hard, moist		
35		08	3.6	NA	–	–	Silt with Sand and Gravel (ML), mostly dark yellowish orange (10YR6/6) and pale yellowish brown (10YR6/2) with trace of moderate reddish brown (10R4/6), hard		15% fine to medium Sand, subrounded, few lenses of sandier zones 5% fine to coarse Gravel, subangular to rounded, some flat and elongated
							Silt (ML) colored as above		Trace Sand
							Silt (ML) as above		
40		09	3.6	NA	–	–	Silt (ML), hard, moist		Laminae with manganese oxide
							Silt with Sand and fine Gravel (ML)		Total Depth = 42.0 ft
45									

Prepared by: *Kenneth R. Davis* — Kenneth R. Davis — *07-19-02* Date

Checked by: *[signature]* — Michelle R. Blanton — *07/23/02* Date

Approved by: *[signature]* — Bruce J. Haas — *07/29/02* Date

LITHOLOGIC LOG	BORING/WELL NO: DPT-520L3	PAGE 1 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 15:25 on 02-24-02	Drill End (time/date): 17:30 on 02-24-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 42 ft
Logged By: T. Campbell	Coordinates: E -3157.98 N -7328.19	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
		01	–	Hand Augered	–	–	Silt with Sand (ML), nonplastic, moderate yellowish brown (10YR5/4) to dark yellowish brown (10YR4/2), moist		Ground elevation = 396.86 ft amsl Grass at land surface 25% (decreasing with depth) fine Sand
		02	–	Hand Augered	–	–	Silt with Sand (ML) as above Silt (ML), colored as above with pale yellow brn (10YR6/2)		Trace fine Sand
		03	–	Hand Augered	–	–	Silt (ML) as above		Trace organics Trace manganese oxide
		04	–	Hand Augered	–	–	Silt (ML) as above		
		05	–	Hand Augered	–	–	Silt (ML), moderate yellowish brown (10YR5/4), wet		
5		06	–	Hand Augered	–	–	Silt (ML) as above		Perched zone (standing water in borehole) at 5.5 ft
		07	–	NA	–	–	Silt (ML), nonplastic, light brown (5YR5/6) with trace pale yellowish brown (10YR6/2), hard, moist		Trace Clay Trace manganese oxide
10		08	–	NA	–	–	Silt (ML) as above but low to medium plasticity		20% Clay
15		09	–	NA	–	–	Silt (ML) as above		
20		10	–	NA	–	–	Sandy Silt (ML), low to medium plasticity,dark yellowish orange (10YR6/6) to pale yellowish brown (10YR6/2), hard, moist Sandy Silt with Gravel (ML) colored as above with lesser moderate reddish brown (10YR4/6), moist		40% Silt 20% Clay Fine Sand, subangular to subrounded 30% Silt Fine Sand, subangular to rounded Fine to coarse Gravel
25		11	–	NA	–	–	Poorly Graded Sand with Silt (SP-SM), nonplastic, light brown (5YR5/6) , hard, moist *With blebs of Silty Clay (CL), medium plasticity, light gray (N7), hard, moist*		Fine Sand, subangular to rounded Trace Clay 10% fine Sand, subangular to subrounded
30		12	–	NA	–	–	Poorly Graded Sand with Silt (SP-SM), nonplastic, mottled pale reddish brown (10R5/4) and pinkish gray (5YR8/1), hard, moist Becoming mostly pale reddish brown (10R5/4)		Fine Sand, angular to subrounded

LITHOLOGIC LOG	BORING/WELL NO: DPT-520L3	PAGE 2 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 15:25 on 02-24-02	Drill End (time/date): 17:30 on 02-24-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 42 ft
Logged By: T. Campbell	Coordinates: E -3157.98 N -7328.19	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
		13	–	NA	–	–	Poorly Graded Sand with Silt (SP-SM), nonplastic, grayish orange (10YR7/4) to dark yellowish orange (10YR6/6), hard, moist		
							Clayey Silt (ML), medium plasticity, pale reddish brown (10R4/2) with trace grayish red (10R5/4)		40% Clay
		14	–	NA	–	–	Clayey Silt (ML) as above		
							Poorly Graded sand with Silt (SP-SM) as 30.0-32.9 ft		
35							Poorly Graded Sand with Silt (SP-SM), light brown (5YR5/6) to pale yellowish brown (10YR6/2)		Fine Sand, subrounded to rounded 20% Silt With fine to coarse Gravel, subangular to subrounded
							Poorly Graded Sand (SP), moderate reddish orange (10YR6/6), very soft, wet Below 36.5 ft, grading to Silt (ML), colored as above with grayish orange (10YR7/4), firm, moist		Fine Sand, subrounded to rounded Trace manganese oxide
40		15	–	NA	–	–	Silt (ML) as above		Total Depth = 42.0 ft
45									

Prepared by: Kenneth R. Davis — Kenneth R. Davis — Date: 07-19-02

Checked by: Michelle R. Blanton — Date: 07/23/02

Approved by: Bruce K Haas — Date: 07/29/02

LITHOLOGIC LOG	BORING/WELL NO: DPT-531L3	PAGE 1 of 1
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 10:45 on 02-25-02	Drill End (time/date): 12:15 on 02-25-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 28.8 ft
Logged By: T. Campbell	Coordinates: E -3103.44 N -7307.01	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
5		01	NA	Hand Augered	–	–	Silt (ML), nonplastic, moderate yellowish brown (10YR5/4) to pale yellowish brown (10YR6/2), moist		<u>Ground elevation = 396.16 ft amsl</u> Grass at surface Trace organics Trace roots Trace fine Sand
		02	4.0	NA	–	–	Silt (ML) as above but hard		Trace Clay Trace manganese oxide
10		03	4.0	NA	–	–	Silt (ML), nonplastic, dark yellowish orange (10YR6/6), hard, moist Mottled with pale yellowish brown (10YR6/2) below 11 ft - increasing with depth		Trace fine Sand Clay content increasing to 10% with depth Trace manganese oxide
15		04	4.0	NA	–	–	Silt (ML) as above		Trace fine Gravel, angular 16.7-17.2 ft: Zone of clayey silt, light gray (N7)
20		05	4.0	NA	–	–	Sandy Silt (ML), pale yellowish brown (10YR6/2) to dark yellowish orange (10YR6/6), hard, moist Deformed light gray (N7) clayey silt nodule over light gray (N7) sand lens (0.25 to 0.5 inches thick) at 75° angle No description available		20% fine Sand, subangular to subrounded Fine Sand, subangular to subrounded Trace Gravel, angular, frosted grains, flattened and elongated
25		06	4.0	NA	–	–	Sand with Silt (SP-SM), mottled dark yellowish orange (10YR6/6), light brown (5YR5/6), and pinkish gray (5YR5/1), hard, moist		Fine Sand, subangular to rounded 25% Silt Mottles as above but tending toward high angle, some mottles appear "stretched" Containing separate zones with clay and silty sand 25.5-26.0 ft: trace Gravel, subangular to rounded, some frosting, possible microfractures
		07	2.8	NA	–	–	Sand with Silt (SP-SM) as above Poorly Graded Sand with Silt (SP-SM), pinkish gray (5R8/1), hard, moist		Motting at less high angle, more random High angle contact at 28.0 ft Very fine Sand, friable Refusal at 28.8 ft

Prepared by: Kenneth R. Davis *Kenneth R. Davis* Date 07-19-02

Checked by: Michelle R. Blanton *[signature]* Date 07/23/02

Approved by: Bruce J. Haas *[signature]* Date 07/29/02

LITHOLOGIC LOG	BORING/WELL NO: DPT-590L3	PAGE 1 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 08:10 on 02-24-02	Drill End (time/date): 10:50 on 02-24-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 42 ft
Logged By: T. Campbell	Coordinates: E -2837.22 N -7192.17	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
		01	--	Hand Augered	--	--	Poorly Graded Sand with Silt (SP-SM), dark yellowish orange (10YR6/6) to moderate yellowish brown (10YR5/4), moist		Ground elevation = 3[illegible].11 ft amsl Grass at land surface Fine Sand, 25% Silt
		02	--	Hand Augered	--	--	Silt and Clay (ML/CL), nonplastic, colored as above with very pale orange (10YR8/2), soft, moist		Approximately 40% Silt
		03	--	Hand Augered	--	--	Silt and Clay (ML/CL) as above		
		04	--	Hand Augered	--	--	Silt and Clay (ML/CL) as above		
5		05	--	Hand Augered	--	--	Silt and Clay (ML/CL) as above		Trace fine Sand
		06	--	Hand Augered	--	--	Silt and Clay (ML/CL) as above		
10		07	--	NA	--	--	Poorly Graded Sand with Silt (SP-SM), nonplastic, colored as above, firm, moist		Fine Sand 40% Silt Trace organics at 7-10 ft
		08	--	NA	--	--	Poorly Graded Sand with Silt (SP-SM), as above Grading to Clayey Silt (ML), nonplastic, colored as above, moist		Trace organics, especially 11.5-12.8 ft 25% Clay Trace fine Sand
15		09	--	NA	--	--	Clayey Silt (ML) as above Grading to Silty Clay (CL), low to medium plasticity, dark yellowish orange (10YR6/6) to medium yellowish brown (10YR5/4) and very pale orange (10YR8/2), moist		35% Silt Trace (<1%) organics Trace Gravel at 15.3-18.5 ft
							Sandy Clay (CL), low plasticity, colored as above, moist		35% fine Sand, angular to subangular Trace fine Gravel
20		10	--	NA	--	--	Sandy Clay (CL), medium plasticity (increasing with depth), dark yellowish orange (10YR6/6) to pale yellowish brown (10R6/2), firm to hard, moist		Fine to coarse Gravel, increasing content with depth .
		11	--	NA	--	--	Sandy Clay (CL) as above		
25							Well Graded Sand with Clay and Gravel (SW-SC), low plasticity, dark yellowish orange (10YR6/6), moist With blebs of Lean Clay with Silt (CL), medium plasticity, medium light gray (N6), moist		Fine to coarse Sand, subangular 30% Clay 20% Gravel, fine to coarse, angular to rounded, quartz and chert
		12	--	NA	--	--	Well Graded Sand with Clay and Gravel (SW-SC) with blebs of Lean Clay with Silt (CL) as above		
							Poorly Graded Sand with Silt (SP-SM), light brown (5YR5/6), hard, moist		Fine Sand, trace medium Sand, angular to subangular 20% Silt
30							Well Graded Sand with Clay and Gravel (SW-SC), with blebs of Lean Clay with Silt (CL) as 23-26 ft		Some (<20%) Gravel

LITHOLOGIC LOG	BORING/WELL NO: DPT-590L3	PAGE 2 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 08:10 on 02-24-02	Drill End (time/date): 10:50 on 02-24-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 42 ft
Logged By: T. Campbell	Coordinates: E -2837.22 N -7192.17	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
							Well Graded Sand with Clay and Gravel (SW-SC), with blebs of Lean Clay with Silt (CL) as 23-26 ft		Some (<20%) Gravel
		13	--	NA	--	--	Lean Clay with Silt (CL/ML), medium plasticity, mottled light brown (5YR5/6) and medium light gray (N6), moist		30% Silt Few Sand lenses, fine (trace medium) grained, increasing Sand content with depth
35		14	--	NA	--	--	Lean Clay with Silt (CL/ML) as above		
							Poorly Graded Sand with Silt (SP-SM), nonplastic, mostly light brown (5YR5/6) with few light gray (N7) mottles, moist		Fine Sand, subangular to rounded 20% Silt 10% Clay Light gray mottled areas have 40% clay and silt
							Silt (ML), nonplastic, light brown (5YR5/6), hard, moist		30% Clay. Trace mica
							Silt (ML), nonplastic, light brown (5YR5/6), hard, moist		30% Clay Increasing fine Sand content with depth Trace mica
40		15	--	NA	--	--	Silt (ML), nonplastic, light gray (N7), soft, moist		Trace fine Sand, micaceous
							Poorly Graded Sand with Silt (SP-SM), nonplastic, light gray (N7), firm		Fine Sand, subangular to subrounded 40% Silt, micaceous
							Poorly Graded Sand (SP), light brown (5YR5/6), wet		Fine Sand, subangular to rounded Some f. Gravel, subrounded to rounded at 41.5-41.7 ft Trace manganese oxide
									Total Depth = 42.0 ft
45									

Prepared by: Kenneth R. Davis — Kenneth R. Davis — Date: 07-19-02

Checked by: Michelle R. Blanton — Date: 07/23/02

Approved by: Bruce J. Haas — Date: 07/29/02

LITHOLOGIC LOG	BORING/WELL NO: DPT-620L3	PAGE 1 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 11:20 on 02-24-02	Drill End (time/date): 14:30 on 02-24-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 42 ft
Logged By: T. Campbell	Coordinates: E -2697.95 N -7134.77	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
									Ground elevation = 395.01 ft amsl
5		01	NA	Hand Augered	–	–	Sandy Silt (ML), nonplastic, moderate brown (5YR4/4) - mottled with light olive gray (5Y6/1) below 1.5 ft, soft, moist		Grass at land surface
10		02	4.0	NA	–	–	Silt with Clay (ML), nonplastic, pale yellowish brown (10YR6/2) to medium yellowish brown (10YR5/4), firm, moist		20% Clay Trace fine Sand
		03	4.0	NA	–	–	Silt with Clay (ML) as above		
15		04	4.0	NA	–	–	Silt with Clay (ML) as above but mottled dark yellowish orange (10YR6/6) and light gray (N7)		
							Silt with Clay (ML) as above		Increasing Clay content, trace fine Sand
20		05	3.5	NA	–	–	Silt with Clay (ML) as above		Trace fine to coarse Gravel at 18.4 ft Increasing Gravel content with depth
							Well Graded Gravel with Clay and Sand (GW-GC), colored as above with moderate reddish brown (10R4/6), hard, moist		Fine to coarse Gravel, subrounded to rounded 20% Clay as matrix 20% fine to coarse Sand, subangular to rounded 10% Silt
							Clayey Silt (CL/ML), medium plasticity, light brown, hard, moist		40% each Clay and Silt 20% fine Sand, trace Gravel
							Poorly Graded Sand with Silt (SP-SM), medium light gray (N6), moist		Fine Sand, subangular to rounded Trace fine to coarse Gravel, subangular to subrounded
25		06	–	NA	–	–	Silty Clay (CL), medium plasticity		15%, increasing to 70% with depth, Silt Trace Gravel
							Poorly Graded Sand with Silt and Gravel (SP-SM), dark yellowish orange (10YR6/6) to light brown (5YR5/6), hard, moist		Fine Sand, subangular to rounded Fine to coarse Gravel, subrounded to rounded
30		07	3.2	NA	–	–	Poorly Graded Sand with Silt (SP-SM), mottled light brown (5YR5/6) and light gray (N7) - becoming light brown (5YR5/6) with depth, hard, moist		35% Silt Micaceous

LITHOLOGIC LOG	BORING/WELL NO: DPT-620L3	PAGE 2 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 11:20 on 02-24-02	Drill End (time/date): 14:30 on 02-24-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 42 ft
Logged By: T. Campbell	Coordinates: E -2697.95 N -7134.77	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
		08	2.6	NA	–	–	Poorly Graded Sand with Silt (SP-SM), light brown (5YR5/6), hard (very soft at 30.6-31.8 ft), moist		35% Silt Micaceous
							Poorly Graded Sand with Silt (SP-SM) as above but firm and wet		Increasing mica content
35		09	–	NA	–	–	Poorly Graded Sand with Silt (SP-SM), light brown (5YR5/6) - becoming dark yellowish brown (10YR4/2) with depth, wet		Fine Sand, subrounded to rounded 15% Silt
40		10	–	NA	–	–	Poorly Graded Sand with Silt (SP-SM) as above but very soft		Total Depth = 42.0 ft
45									

Prepared by: Kenneth R. Davis (signature) 07-19-02
Kenneth R. Davis — Date

Checked by: (signature) 07/23/02
Michelle R. Blanton — Date

Approved by: (signature) 07/29/02
Bruce J. Haas — Date

LITHOLOGIC LOG	BORING/WELL NO: DPT-670L3	PAGE 1 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 16:20 on 02-26-02	Drill End (time/date): 09:45 on 02-27-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 40 ft
Logged By: T. Campbell	Coordinates: E -2475.31 N -7036.34	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
		01	2.4	NA	–	–	Silt (ML), nonplastic, pale yellowish brown (10YR6/2) to moderate yellowish brown (10YR5/4), firm, wet		Ground elevation = 392. 56 ft amsl Grass at surface Trace fine Sand Trace organics
5		02	1.4	NA	–	–	Silt (ML) as above but moist		Trace organics at 5.0-5.2 ft
10		03	4.0	NA	–	–	Silt (ML) as above		Organics below 9.0 ft, especially at 9.2 ft and 10.2-10.7 ft Trace manganese oxide
15		04	4.0	NA	–	–	Silt (ML) as above Silt (ML), low plasticity, mottled dark yellowish orange (10YR6/6) and pale yellowish brown (10YR6/2), hard, moist		15-25% Clay Trace (increasing content with depth) fine Sand, subangular to subrounded Trace fine gravel
20		05	–	NA	–	–	Poorly Graded Sand with Silt (SP-SM), mottled colors as above, moist Silt (ML), low plasticity, mottled moderate reddish brown (10R4/6) and pale yellowish brown (10YR6/2), hard, moist		Fine Sand, subrounded to rounded 15-25% Clay, yellow mottled areas have greater clay content and greater plasticity Sandy Gravel layer at 18.3-18.5 ft
		06	2.5	NA	–	–	Silt (ML) as above		20-24 ft sample was disturbed during collection
25		07	2.7	NA	–	–	Well Graded Sand with Gravel (SW), moderate yellowish brown (10YR5/4) to moderate reddish brown (10R4/6), moist Grading at 26 ft to Poorly Graded Sand with Silt (SP-SM), moderate reddish brown (10R4/6) with few yellowish gray (5Y8/1) mottles and laminae, hard, moist		Fine to coarse Sand and Gravel, angular to subrounded Fine Sand, subrounded to rounded Micaceous
30		08	2.4	NA	–	–	Poorly Graded Sand with Silt (SP-SM) as above but without laminae and wet		Sand becoming coarser with depth

LITHOLOGIC LOG	BORING/WELL NO: DPT-670L3	PAGE 2 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 16:20 on 02-26-02	Drill End (time/date): 09:45 on 02-27-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 40 ft
Logged By: T. Campbell	Coordinates: E -2475.31 N -7036.34	Protective Level: D

DEPTH (ft)	SAMPLE INTERVAL	SAMPLE NUMBER	SAMPLE RECOVERY (ft)	SPT RESULT 6"-6"-6"-6" (N)	HEALTH/SAFETY VOC	HEALTH/SAFETY RAD	LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
					--	--	Poorly Graded Sand with Silt (SP-SM), moderate reddish brown (10R4/6) with few yellowish gray (5Y8/1) mottles, hard, wet		Subrounded to rounded Sand Micaceous
35		09	2.6	NA	--	--	Well Graded Gravel with Silt and Sand (GW-GM), dark yellowish orange (10YR6/6) to moderate yellowish brown (10YR5/4), wet		Fine to coarse Sand and Gravel, subangular to rounded, few flat and elongated grains
40		10	Trace	NA	--	--	Gravel		Sample could not be removed from sampler. Cleaned sample out with pressure washer. Total Depth = 40.0 ft
45									

Prepared by: Kenneth R. Davis — Kenneth R. Davis — Date: 07-19-02

Checked by: [signature] — Michelle R. Blanton — Date: 07/23/02

Approved by: [signature] — Bruce J. Haas — Date: 07/29/02

LITHOLOGIC LOG	BORING/WELL NO: SB-04	PAGE 1 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 09:00 on 03-08-02	Drill End (time/date): 11:05 on 03-08-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 40 ft
Logged By: T. Campbell	Coordinates: E -1377.72 N -5971.77	Protective Level: D

DEPTH (ft)	SAMPLE			SPT RESULT	HEALTH/ SAFETY		LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
	INTERVAL	NUMBER	RECOVERY (ft)	6"-6"-6"-6" (N)	VOC	RAD			
5		01	--	Hand Auger	--	--	Silt (ML), nonplastic, pale yellowish brown (10YR6/2) to dark yellowish brown (10YR4/2), soft, moist		Ground elevation = 382.28 ft amsl Grass at surface Trace fine Sand
		02	0.5	NA	--	--	Silt (ML), nonplastic, indistinctly mottled pale yellowish brown (10YR6/2) and moderate yellowish brown (10YR5/4), hard, moist		Trace manganese oxide
10		03	3.0	NA	--	--	Silt (ML) as above but becoming mostly pale yellowish brown (10YR6/2) and soft to very soft		No manganese oxide below 10 ft
15		04	4.0	NA	--	--	Silt (ML), low plasticity, mottled pale yellowish brown (10YR6/2), hard, moist		Clay content increasing to 30%
20		05	3.9	NA	--	--	Silt (ML) as above		10% Clay Trace fine Gravel
		06	3.9	NA	--	--	Silt (ML), nonplastic, hard, moist		20.0-20.5 ft = slough from above Trace fine to coarse Gravel, subangular to subrounded, some grains flattened and elongated Few Sandy Silt zones.
25		07	3.9	NA	--	--	Mottled Sandy Silt (ML) and Clayey Silt (ML), nonplastic to medium plasticity, light brown (5YR5/6) to light gray (N7), moist		24.0-24.5 ft = slough from above 15% fine Sand and 15% Clay in separate mottled areas
30		08	4.0	NA	--	--	Mottled Sandy Silt (ML) and Clayey Silt (ML) as above		Micaceous

LITHOLOGIC LOG	BORING/WELL NO: SB-04	PAGE 2 of 2
Facility: Paducah Gaseous Diffusion Plant, Paducah, KY		Site: Site 3A
Project No: DO 110	Client/Project: USDOE/PGDP Site 3A Seismic Assessment	
Contractor: SAIC	Drill Contractor: Greg In-Situ	Driller: Mike Davis
Drill Start (time/date): 09:00 on 03-08-02	Drill End (time/date): 11:05 on 03-08-02	Borehole Dia: 2 inch
Drill Method/Rig Type: Direct Push with Track Rig D-24 (MacroCore 4-ft Sampler)		Total Depth: 40 ft
Logged By: T. Campbell	Coordinates: E -1377.72 N --5971.77	Protective Level: D

DEPTH (ft)	SAMPLE			SPT RESULT 6"-6"-6"-6" (N)	HEALTH/ SAFETY		LITHOLOGIC DESCRIPTION	GRAPH LOG	COMMENTS
	INTERVAL	NUMBER	RECOVERY (ft)		VOC	RAD			
					--	--	Mottled Sandy Silt (ML) and Clayey Silt (ML), nonplastic to low plasticity, light brown (5YR5/6) to light gray (N7), moist		15% fine Sand and 15% Clay in separate mottled areas Micaceous
35		09	1.4	NA	--	--	Well Graded Sand with Silt (SW-SM), moderate yellowish brown (10YR5/4), wet Grading at base of sample to Gravel		Fine to coarse Sand, subangular to subrounded 20% Silt Trace fine to coarse Gravel, subangular to rounded
40		10	Trace	NA	--	--	Well Graded Gravel with Sand (GW), moderate yellowish brown (10R5/4) to grayish orange (10YR7/4), wet		Sample was loose, poured from sampler Fine to coarse Gravel, angular to subrounded 40% fine to coarse Sand, quartz and chert Fine sand is rounded Medium and coarse sand is angular to subrounded Total Depth = 40.0 ft (refusal)

Prepared by: Kenneth R. Davis   07-19-02
Kenneth R. Davis   Date

Checked by: [signature]   07/23/02
Michelle R. Blanton   Date

Approved by: [signature]   07/29/02
Bruce J. Haas   Date

ATTACHMENT D-III

^{14}C AGE DATING LABORATORY ANALYSES

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BETA

Consistent Accuracy Delivered On Time.

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MR. DARDEN HOOD
Director

Mr. Ronald Hatfield
Mr. Christopher Patrick
Deputy Directors

April 29, 2002

INFORMATION ONLY

Ms. Kay Dabney
United States Enrichment Corporation
Paducah Gaseous Diffusion Plant
P.O. Box 1410
Paducah, KY 42001
USA

RE: Radiocarbon Dating Results For Samples CCFRD460-1, CCFRD560-1, CCFRD610-1, CCFRD736-1, CCFRD736-2, CCGTD440L2, CCGTD500L2, CCGTD620L3, CCGTD670L3, CCGTSB03C04, CCGTSB03C36, CCGTSB06C11

Dear Ms. Dabney:

Enclosed are the radiocarbon dating results for 12 samples recently sent to us. They each provided plenty of carbon for accurate measurements and all the analyses went normally. As usual, the method of analysis is listed on the report with the results and calibration data is provided where applicable.

As always, no students or intern researchers who would necessarily be distracted with other obligations and priorities were used in the analyses. We analyzed them with the combined attention of our entire professional staff.

If you have specific questions about the analyses, please contact us. We are always available to answer your questions.

Our invoice has been sent separately. Our copy is enclosed. Thank you for your prior efforts in arranging payment. As always, if you have any questions or would like to discuss the results, don't hesitate to contact me.

Sincerely,

Darden Hood

BETA

BETA ANALYTIC INC.

DR. M.A. TAMERS and MR. D.G. HOOD

UNIVERSITY BRANCH
4985 S.W. 74 COURT
MIAMI, FLORIDA, USA 33155
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REPORT OF RADIOCARBON DATING ANALYSES

Ms. Kay Dabney — Report Date: 4/29/02

United States Enrichment Corporation — **INFORMATION ONLY** — Material Received: 4/12/02

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 166595	1160 +/- 40 BP	-23.0 o/oo	1190 +/- 40 BP

SAMPLE : CCFRD460-1
ANALYSIS : AMS-Advance delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal AD 720 to 740 (Cal BP 1230 to 1210) AND Cal AD 760 to 960 (Cal BP 1190 to 990)

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 166596	9160 +/- 50 BP	-22.6 o/oo	9200 +/- 50 BP

SAMPLE : CCFRD560-1
ANALYSIS : AMS-Advance delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 8560 to 8280 (Cal BP 10510 to 10230)

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 166598	7230 +/- 40 BP	-23.4 o/oo	7260 +/- 40 BP

SAMPLE : CCFRD610-1
ANALYSIS : AMS-Advance delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 6220 to 6020 (Cal BP 8160 to 7970)

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 166599	11130 +/- 60 BP	-22.5 o/oo	11170 +/- 60 BP

SAMPLE : CCFRD736-1
ANALYSIS : AMS-Advance delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 11440 to 11290 (Cal BP 13390 to 13240) AND Cal BC 11270 to 11040 (Cal BP 13220 to 12990)

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 166600	10760 +/- 50 BP	-22.6 o/oo	10800 +/- 50 BP

SAMPLE : CCFRD736-2
ANALYSIS : AMS-Advance delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 11040 to 10850 (Cal BP 12990 to 12800) AND Cal BC 10790 to 10690 (Cal BP 12740 to 12640)

Dates are reported as RCYBP (radiocarbon years before present, "present" = 1950A.D.). By international convention, the modern reference standard was 95% of the C14 content of the National Bureau of Standards' Oxalic Acid & calculated using the Libby C14 half life (5568 years). Quoted errors represent 1 standard deviation statistics (68% probability) & are based on combined measurements of the sample, background, and modern reference standards.

Measured C13/C12 ratios were calculated relative to the PDB-1 international standard and the RCYBP ages were normalized to -25 per mil. If the ratio and age are accompanied by an (*), then the C13/C12 value was estimated, based on values typical of the material type. The quoted results are NOT calibrated to calendar years. Calibration to calendar years should be calculated using the Conventional C14 age.

BETA ANALYTIC INC.

DR M A TAMERS and MR D G HOOD

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REPORT OF RADIOCARBON DATING ANALYSES

Ms. Kay Dabney

INFORMATION ONLY

Report Date: 4/29/02

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 166602	13540 +/- 60 BP	-23.3 o/oo	13570 +/- 60 BP

SAMPLE : CCGTD440L2
ANALYSIS : AMS-Advance delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 14750 to 14000 (Cal BP 16700 to 15950)

Beta - 166603	3770 +/- 50 BP	-23.5 o/oo	3790 +/- 50 BP

SAMPLE : CCGTD500L2
ANALYSIS : AMS-Advance delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 2400 to 2380 (Cal BP 4350 to 4330) AND Cal BC 2360 to 2120 (Cal BP 4300 to 4060)
Cal BC 2100 to 2040 (Cal BP 4050 to 3990)

Beta - 166604	13850 +/- 60 BP	-22.2 o/oo	13900 +/- 60 BP

SAMPLE : CCGTD620L3
ANALYSIS : AMS-Advance delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 15100 to 14340 (Cal BP 17050 to 16300)

Beta - 166605	15620 +/- 70 BP	-22.2 o/oo	15670 +/- 70 BP

SAMPLE : CCGTD670L3
ANALYSIS : AMS-Advance delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 17220 to 16330 (Cal BP 19170 to 18280)

Beta - 166606	4190 +/- 40 BP	-22.1 o/oo	4240 +/- 40 BP

SAMPLE : CCGTSB03C04
ANALYSIS : AMS-Advance delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 2910 to 2860 (Cal BP 4860 to 4810) AND Cal BC 2810 to 2750 (Cal BP 4760 to 4700)
Cal BC 2720 to 2700 (Cal BP 4670 to 4650)

Dates are reported as RCYBP (radiocarbon years before present, "present" = 1950A.D.). By international convention, the modern reference standard was 95% of the C14 content of the National Bureau of Standards' Oxalic Acid & calculated using the Libby C14 half life (5568 years). Quoted errors represent 1 standard deviation statistics (68% probability) & are based on combined measurements of the sample, background, and modern reference standards.

Measured C13/C12 ratios were calculated relative to the PDB-1 international standard and the RCYBP ages were normalized to -25 per mil. If the ratio and age are accompanied by an (*), then the C13/C12 value was estimated, based on values typical of the material type. The quoted results are NOT calibrated to calender years. Calibration to calendar years should be calculated using the Conventional C14 age.

FROM : BETA ANALYTIC FAX NO. : 305-663-0964 Apr. 29 2002 04:01PM P4

BETA

BETA ANALYTIC INC.

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REPORT OF RADIOCARBON DATING ANALYSES

Ms. Kay Dabney

INFORMATION ONLY

Report Date: 4/29/02

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 166607 SAMPLE : CCGTSB03C36 ANALYSIS : AMS-Advance delivery MATERIAL/PRETREATMENT : (organic sediment): acid washes 2 SIGMA CALIBRATION : Cal BC 6220 to 6040 (Cal BP 8170 to 7990)	7230 +/- 40 BP	-21.9 o/oo	7280 +/- 40 BP
Beta - 166608 SAMPLE : CCGTSB06C11 ANALYSIS : AMS-Advance delivery MATERIAL/PRETREATMENT : (organic sediment): acid washes 2 SIGMA CALIBRATION : Cal BC 5760 to 5650 (Cal BP 7710 to 7600)	6790 +/- 40 BP	-22.8 o/oo	6830 +/- 40 BP

Dates are reported as RCYBP (radiocarbon years before present, "present" = 1950A.D.). By International convention, the modern reference standard was 95% of the C14 content of the National Bureau of Standards' Oxalic Acid & calculated using the Libby C14 half life (5568 years). Quoted errors represent 1 standard deviation statistics (68% probability) & are based on combined measurements of the sample, background, and modern reference standards.

Measured C13/C12 ratios were calculated relative to the PDB-1 international standard and the RCYBP ages were normalized to -25 per mil. If the ratio and age are accompanied by an (*), then the C13/C12 value was estimated, based on values typical of the material type. The quoted results are NOT calibrated to calendar years. Calibration to calendar years should be calculated using the Conventional C14 age.